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A Survey of Bell System Progress in Electronic Switching*

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This article is a survey-type discussion of the Bell System's No. 1 Electronic Switching System for central office use and No. 101 Electronic Switching System for business use. For both systems it presents background history and descriptions of the major subsystems and components. It also covers recent manufacture, installation and commercial service of these two systems.

I. INTRODUCTION

Two Electronic Switching Systems have been developed by Bell Telephone Laboratories for general application in the Bell System; both are now in quantity manufacture by the Western Electric Company. One of these, known as No. 1 ESS, is designed for local central offices, and is the commercial successor to the Morris Electronic Central Office. Its system organization is also potentially suitable for tandem and toll applications. The other system, called No. 101 ESS, is designed to provide electronic private branch exchange services in conjunction with existing electromechanical central offices. It brings to the business community modern PBX and Centrex† features which can be provided economically with this new type of system.

* Originally written for the German Bundespost and published in their 1964 Yearbook of Telecommunications, this article has been updated and is published here by permission for readers of the B.S.T.J.

† The principal features of Centrex are direct inward dialing to extensions, identified outward dialing, and certain switchboard attendant features.

The electronic private branch exchange was the first of the two to be placed in commercial service. On November 30, 1963, the Southern Bell Telephone Company initiated Centrex service to about 100 extensions at the Brown Engineering Company, Cape Kennedy, Florida. Two weeks later service began at the Chrysler Corporation's office, also located at Cape Kennedy. During 1964 and early 1965 No. 101 ESS installations were completed for service at such widely separated locations as New York City, Chicago, Cleveland, Los Angeles, and Washington, D. C.

In 1963 installation by the Western Electric Company of the first commercial No. 1 ESS central office began in a new building at Succasunna, New Jersey, for the New Jersey Bell Telephone Company. After undergoing an extensive series of tests, that system was cut over to commercial service on May 30, 1965. It now serves both residence and business telephone users in that community. Additional No. 1 ESS central offices are being installed and tested in Baltimore, New York City, Norfolk, and Washington, D. C., as well as in several locations to serve military customers; the latter provide four-wire switching of lines and trunks as contrasted to two-wire switching for the commercial offices.

This article surveys the work leading to these two developments and describes the production designs which are inaugurating a new era in switching for the Bell System.

II. EARLY WORK

For many years engineers have been intrigued by the idea of applying electronics to switching. As the switching art and digital technology developed, these ideas and speculations became more definitive. With the very high speed operation of electronic components, it was believed that the principal advantages of common control would be enhanced in that very large offices could be controlled with a single common control without the complications of multiple marker usage. At Bell Telephone Laboratories these ideas led to a formalized attack on the problem, beginning shortly after the close of World War II. The aim of the work was to explore various approaches to the electronic switching problem with the ultimate objective of improving service, reducing costs, and providing greater flexibility while maintaining the high reliability of electromechanical switching.

The early work produced many innovations, and several laboratory switching systems were constructed to explore the basic concepts. Among them was a space-division system employing reed-diode switching

matrices with "end-marking" under control of multi-element gas tubes. This system, known as ECASS[1] (Electronically Controlled Automatic Switching System), was brought to a laboratory demonstration level in 1947. In 1948 exploratory work was carried out on a single highway time-division system using vacuum tube gates and quartz delay lines for memory. This was followed in 1949 with DIAD[2] (Drum Information Assembler and Dispatcher). This was a system having a large memory in common control and a space division reed-diode "end-marked" network.

Research on these systems brougbt valuable insight to both network and common control aspects of electronic switching and provided a firm technical foundation for later work. However, it also pointed up the desirability of new devices for both logic and memory if electronic switching were to become a serious challenge to the highly developed electromechanical systems.

In the early 1950's the transistor (invented at Bell Laboratories in 1948) had reached the stage of development where it could be seriously considered for commercial application. This, together with economical bulk memories based upon the cathode ray and barrier grid tubes, suggested the possibility of developing a commercial electronic switching system. Work on such a system, initiated in 1954, led to a field trial of an electronic central office at Morris, Illinois.

Because of the historical significance of the Morris trial and its impact on subsequent development work, it seems appropriate to present some of the results obtained.

III. THE MORRIS TRIAL

3.1 *The Morris System*

A view of the installation in the Morris central office is shown in Fig. 1. Although the system has been previously described,[3] a brief review of its design will provide useful background.

Fig. 2 is a block diagram of the Morris electronic switching system.[4] Lines and trunks were terminated on a space-division switching matrix having gas tube crosspoints. In this installation the matrix was equipped for 604 customer lines. "End-marking" of the network was under control of a high-speed, stored program, common control system. Because the gas tube crosspoints in the switching network could not carry high-level standard ringing current, each customer was provided with a low-current tone ringer station set. The common control equipment consisted of a central control logic unit associated with barrier grid

Fig. 1 — Electronic central office trial installation at Morris, Illinois.

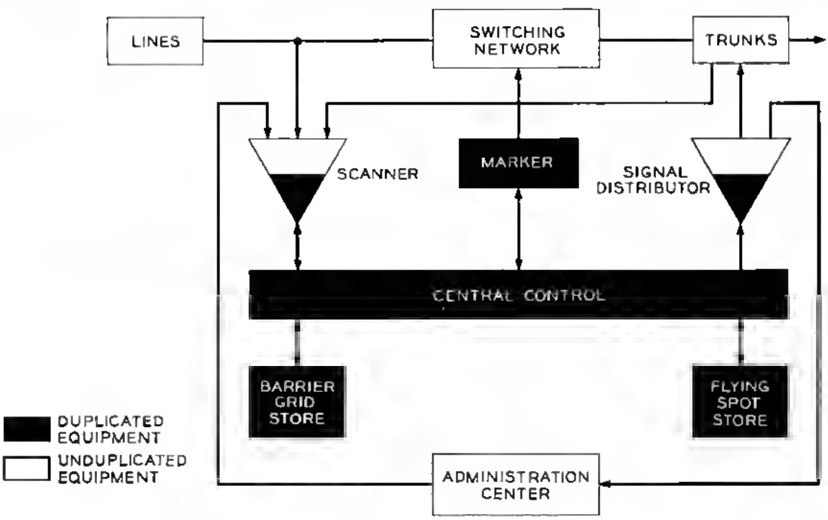

Fig. 2 — Morris ESS block diagram.

stores for temporary memory and a flying spot store for program and translation storage.

The flying spot store was a 2.25 million bit high-speed, random access, semipermanent memory that used a cathode ray tube, a complex optical system, and photographic plates on which program or translation information was placed in the form of a pattern of transparent or opaque spots. Photomultiplier tubes detected the light transmitted through these spots to determine the "1" or "0" condition of the information bit. An ingenious electronic servo system maintained beam position and light intensity with such accuracy that adjacent bits could be placed on 7-mil centers. The 2.25 million bits of program and translation information were stored on four 10 inch $\times$ $12\frac{1}{2}$ inch glass photographic plates. Cycle time of the store was 2.5 microseconds.

The temporary or "scratch pad" memory consisted of two barrier grid tube stores, which provided a memory capacity of 32,768 bits. This memory was also operated on a 2.5 microsecond cycle time.

The semiconductors, transistors, and diodes used in this system were the diffused germanium variety that were available in 1957. In order to insure continuous operation of these devices, the equipment cabinets were air conditioned. In addition, the gas tube switching network required control of ambient temperature within narrow limits for reliable operation. Air conditioning was also required for the two memories because of their high level of heat dissipation.

In spite of the special precautions taken to insure component reliability, it was known at the outset that failures would occur more frequently than could be tolerated for the service continuity required in a switching system. Accordingly, all of the common control equipment and portions of the electronic scanner and signal distributor were provided in duplicate, and arrangements were made to switch automatically from one set of equipment to the other in the event of a malfunction. Also, programs were included in memory to provide automatic fault recognition and diagnosis of the unit in trouble.[5] Since air conditioning was an essential part of the design, this too was provided in duplicate.

The system was installed in the central office in Morris, Illinois, early in 1960, and part-time telephone service was given to a small number of customers beginning in June of that year.[6] Full-time service began in November of 1960 and continued through January of 1962, at which time the trial was terminated. The number of customers and stations served during the trial is shown in Fig. 3.

In addition to the usual telephone service, customers were supplied with one or more special features. One of the most popular of these was

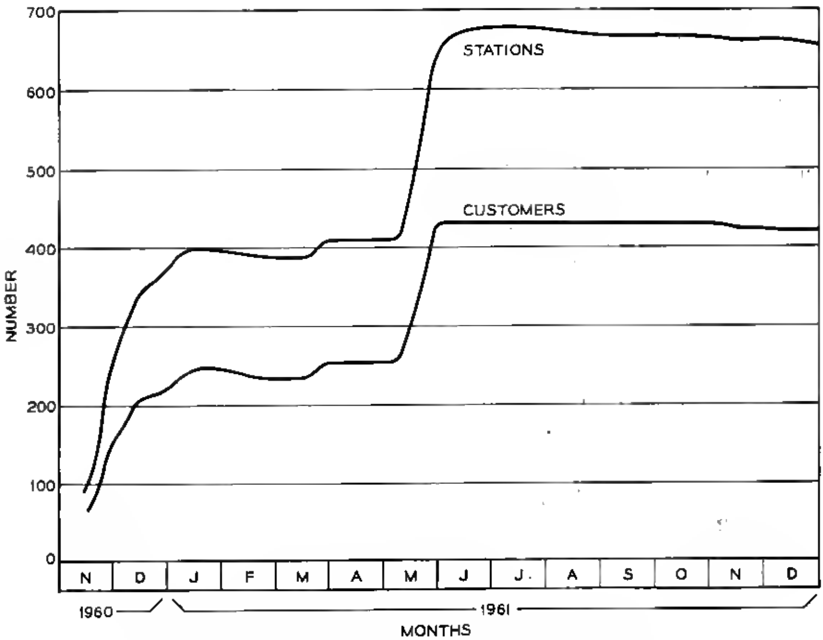

Fig. 3 — Morris ECO — customers and stations.

"abbreviated dialing" by which a two-digit code could be used to reach a seven-digit telephone number. Only four abbreviated codes were made available in the trial. In spite of this limited repertoire, on some lines as many as 50 per cent of all originations were made using this feature. On the average more than 15 per cent of all originations from lines equipped with this service made use of abbreviated dialing.

Another popular feature was "code calling" which in effect provided an intercom in homes equipped with more than one telephone. Dialing a special code and hanging up initiated a coded ring-back to call a particular member of the household to the nearest extension. Cessation of ring indicated to the calling party that the called party had answered.

Three methods were provided to permit the telephone user to have his incoming calls directed to another telephone. One method permitted the routing of calls to a specific preselected alternate number in the Morris office if the user dialed a special code before leaving his phone. When he returned, he dialed another code to cancel the reroute. Another method required the user to call the telephone company business office to indicate the number to which calls should be routed, the time for service to start, and the time for it to be discontinued. This was a useful feature for people who expected to be out of town for extended

periods and wanted to have their calls answered at another telephone. In the third method the user could initiate the transfer to any number in tbe central office by dialing a special code and the number to which he wished the calls to be routed. The service could be cancelled by dialing another special code.

3.2 *Trial Results*

Performance of the Morris electronic switching system was measured in several ways. One way was through service observing on selected lines and record keeping on calls in which irregularities occurred. In the early montbs of the trial, irregularities were much too frequent, but a marked improvement was achieved in February, 1961, as indicated in Fig. 4. A somewhat similar measure of performance, with similar results, was obtained through customer reports, as indicated in Fig. 5.

Tbe marked improvement in February, 1961, was due almost entirely to the introduction of improved programming metbods which have had a marked influence on programming philosophy for the commercial design. This improved programming concept was called "guard and defensive" programming. It provided a means of insuring that information being processed within the system did, in fact, agree with reality. For example, information concerning the busy or idle state of a custom-

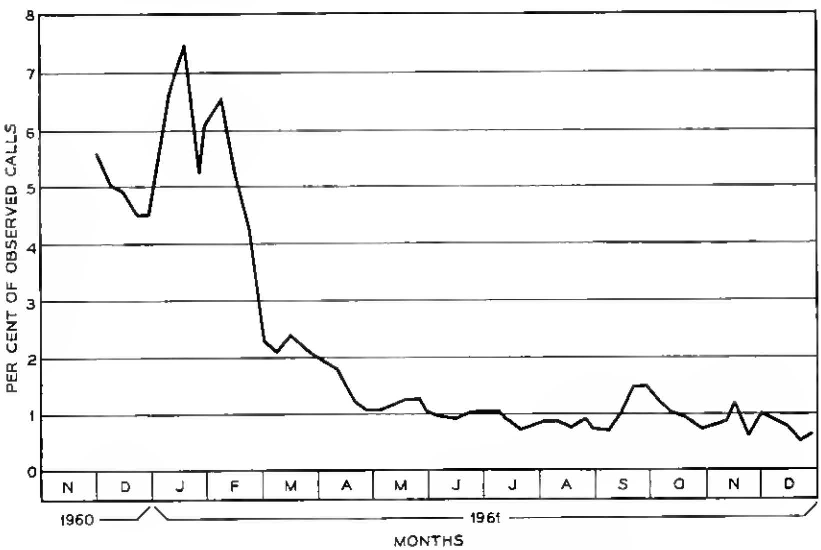

Fig. 4 — Morris ECO — service irregularities.

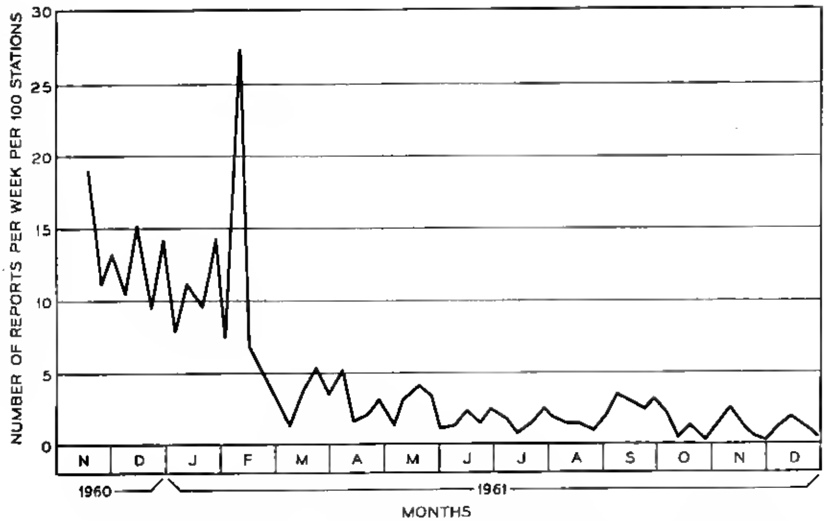

Fig. 5 — Morris ECO — customer reports.

er's line, which is stored in the temporary store, was checked by a guard program every four seconds to determine whether that state agreed with other information concerning that line located elsewhere in the common control equipment. The affect of this important programming change is evident when shown against the background of customer complaints in Fig. 6.

Fig. 6 also shows the period during which improved diagnostic programs for automatic maintenance were installed in the system. The small vertical lines on the Figure indicate dates on which major changes in the program contained in the flying spot store were made. Because of the duplication of the common control equipment, such changes could be readily installed without interrupting customer service. With the facilities provided for processing new photographic plates, the entire program could be changed in about 45 minutes.

In order to aid the maintenance personnel in locating equipment faults, a maintenance dictionary was prepared and became available during the last half of the trial, as indicated in Fig. 6. Whenever a fault occurred in the system, diagnostic routines in the program analyzed the situation and provided a print-out on a teletypewriter associated with the central office equipment. The print-out could then be used as an entry point in the maintenance dictionary to determine which plug-in electronic package required replacement. In most cases in the highly complex central control equipment, the diagnostic print-out and dic-

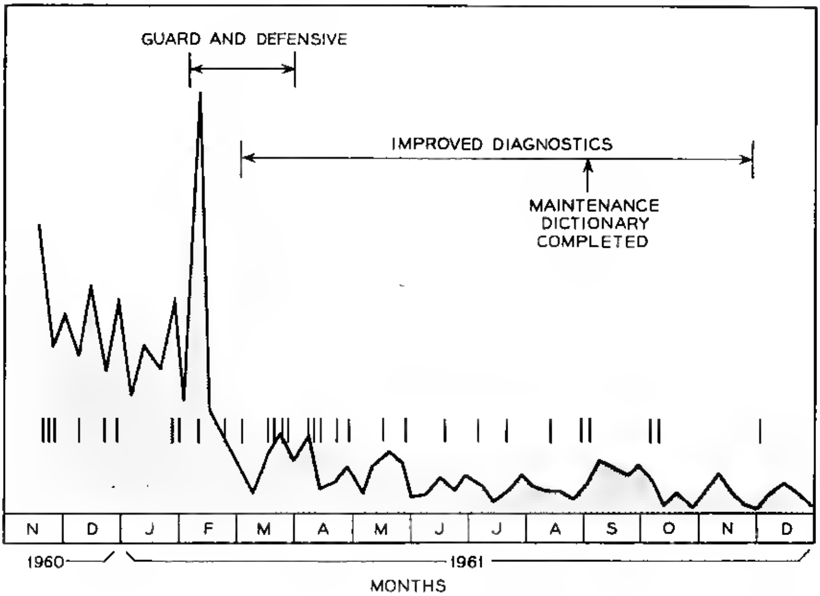

Fig. 6 — Morris ECO — program changes.

tionary could isolate the fault to a single plug-in package. In a relatively small number of fault conditions, a group of several packages might be indicated as the possible source of trouble.

Another measure of system performance is contained in the record of electronic package failures, shown in Fig. 7. It will be noted that the largest number of electronic packages in the system were semiconductor logic packages and that the failure rates for these were very low. As might be anticipated, packages containing relatively high power semiconductors failed at a somewhat greater rate, while electron tube and gas tube failures were highest of all.

Although the failure rates dropped off during the course of the trial, the shape of this trend as seen in Fig. 7 is markedly different from that of the service irregularities and customer reports discussed earlier. It is believed that this difference is due to the guard and defensive programming. The difference gives rise to the concept of "dependability" as a service measure while reserving the term "reliability" as a measure of component performance.

The component failures for the semiconductor logic packages as a function of time are shown in Fig. 8. The marked difference between the failures in the first half and last half of the trial can probably be attrib-

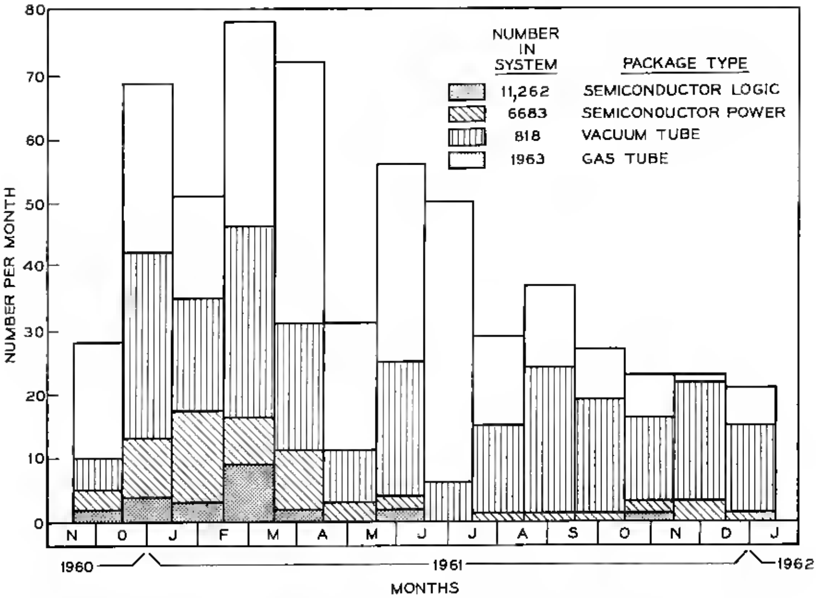

Fig. 7 — Morris ECO — package failures.

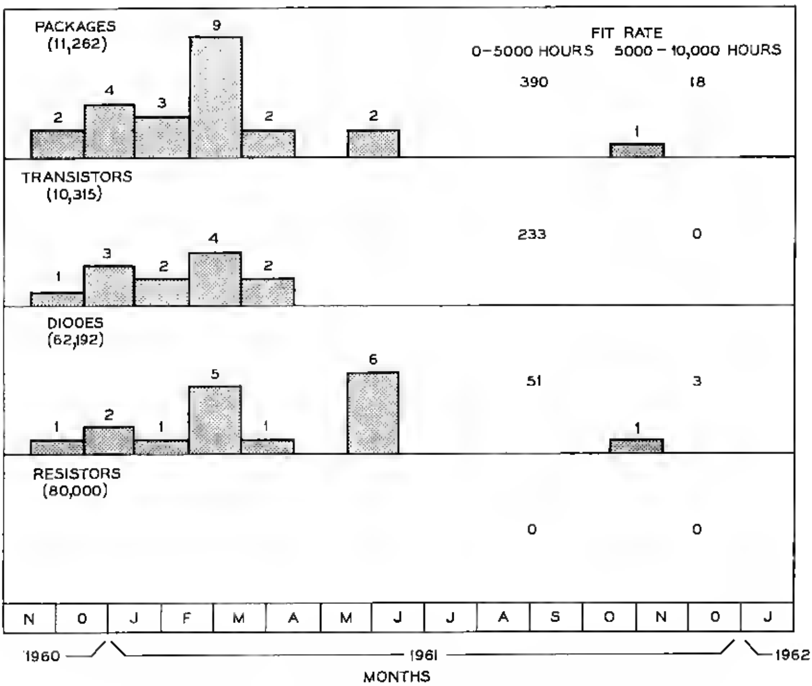

Fig. 8 — Morris ECO — logic package device failures.

uted to less human intervention in system operation as well as to the weeding out of marginal units. The failure rate for the first and last 5,000 hours of system operation is compared in the so-called "fit rate" shown on the right-hand side of the Figure. One fit corresponds to one failure on 10^9 hours of operation.

3.3 *Impact on System Design*

The Morris trial provided important background for the development of No. 1 ESS. In particular, it demonstrated the feasibility of providing dependable service with stored program control which has major advantages in manufacture, maintenance, and flexibility of office administration. The practicability of providing automatic diagnostic programs to assist the maintenance personnel was confirmed. Special programming strategies of guard and defensive programming were evolved to greatly increase system dependability.

The trial also indicated that a major effort should be made to eliminate electron tubes and to remove the requirement for expensive air conditioning equipment. Furthermore, the experience suggested an improvement in the method used for switching between duplicate system equipment so that calls which were in the process of being set up would not be mutilated during the switching interval.

As a result of experience with Morris, the hardware design of No. 1 ESS differs markedly from that used in the trial, although the basic philosophy of stored program control remains the same. A description of this commercial successor to Morris is contained in the next section.

IV. NO. 1 ESS

4.1 *Design Considerations*

Any switching system intended for general Bell System application throughout the United States must cover a broad range in office size and traffic capability and must provide for orderly office growth. An analysis of the Bell System lines in service as of 1960 indicated that 75 per cent of the lines terminated in central office buildings containing over 7500 lines. Fifty per cent were in buildings serving over 19,000 lines and 25 per cent terminated in buildings serving over 32,000 lines. On the other hand, 75 per cent of the central office buildings served less than 3000 lines if one includes community dial offices. An effort was made in the design of No. 1 ESS to provide a configuration witb suffi-

cient growth potential to cover a wide range of needs throughout the Bell System.

The stored program control concept demonstrated in the Morris trial was selected for implementation. In fact, it was concluded that the flexibility of stored program control, made possible by high-speed electronics, is more important for switching systems of the future than is the use of electronics per se. The method is adaptable to the wide range in size and growth and simplifies the introduction of changes in operating methods or service features after installation by changing program rather than office wiring. From the factory point of view, the stored program concept permits uniform production with a minimum of wired options; it also should result in less installation effort both initially and for office growth.

To replace the Morris gas-tube switching matrix, a search was undertaken for a suitable metallic crosspoint having control compatibility with high-speed electronics. This was considered desirable for two principal reasons. First, it would avoid the need for special telephone instruments required at Morris and second, it would simplify testing of lines and trunks. To meet this need for an electronically controlled metallic crosspoint, the ferreed was invented, about which more will be said later.

Economic considerations made it desirable to avoid air conditioning. This was made possible by (1) the advent of silicon epitaxial semiconductor devices, which will withstand higher ambient temperatures than the germanium devices used in Morris, (2) the development of new types of random access memory, to be described later, and (3) the ferreed development already mentioned.

The various considerations of Bell System requirements and the experience gained from Morris led to the design of a system which will serve the needs of offices varying in size from a few thousand lines to a maximum of 65,000 lines. The lower limit is determined strictly by economics because of the relatively fixed and rather substantial cost of the common control portion of the system. The upper limit in number of lines to be handled is determined largely by traffic considerations, the speed of the common control, and configuration of the switching network. In high-traffic offices, such as might be found in metropolitan New York, the maximum number of lines to be served by a single switching system will be substantially lower than the 65,000 maximum mentioned above, largely because of common control speed limitations.

4.2 *System Organization*

The organization of No. 1 ESS is very similar to that of the Morris system, as indicated by the block diagram shown in Fig. 9. It consists of an eight-stage space-division switching network utilizing ferreed crosspoints. A central control logic unit interprets instructions contained in the semipermanent memory and carries out the various operations required in handling the telephone traffic. Temporary memory used in conjunction with central control provides call processing registers and

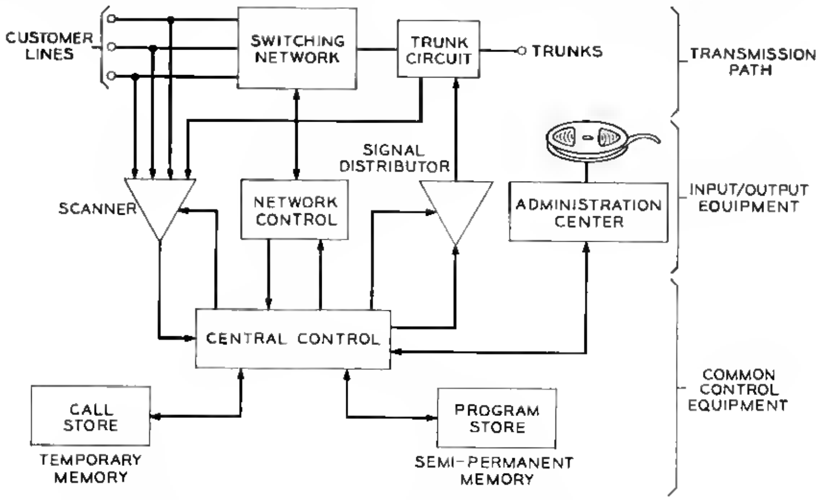

Fig. 9 — No. 1 Electronic Switching System organization.

other "scratch pad" type memory needed in central control operations. Input to this high-speed information processing complex is obtained via scanners which examine the state of lines and trunks on a time-shared basis. When it is addressed by central control, the scanner will examine the state of a particular group of lines and place into the temporary memory information concerning the "on-hook" or "off-hook" state of these lines. Normally lines are scanned at 200-millisecond intervals for detection of originations. Upon detection of an origination, the rate is increased to give a scanning interval of 10 milliseconds. This shorter interval is required to count dial pulses or to detect the outputs of receivers used to convert TOUCH-TONE* calling signals to dc signals.

The signal distributor provides a means for converting the short

* Reg. U.S. Pat. Off.

electronic pulses from central control to appropriate signals on trunks to distant offices. Thus for low-speed outpulsing, central control may request the distributor to close a relay contact, and then the central control will continue to perform many additional logic operations on other calls. Several tens of milliseconds later, at the appropriate time, another order to the distributor would call for opening the relay contact. By this means, the stored program control can perform many complex functions in trunk circuits, thereby minimizing the types and complexity of trunk circuits now found in electromechanical switching offices.

A second output from central control provides for closing the appropriate crosspoints in the switching network, while a third provides information to an administration center. The latter contains the teletypewriter for machine maintenance and a magnetic tape recorder for automatic message accounting information.

4.3 *Design for Dependability*

A more detailed block diagram of No. 1 ESS is shown in Fig. 10. Incoming lines and trunks enter the system at the protector blocks shown at the top of the Figure and thence are connected through a main distributing frame to appropriate portions of the switching network. Electronic control for these network frames is provided over a peripheral unit bus from duplicated central control units. Similar bus arrangements are used for interconnecting program stores and call stores to central control.

This bussing arrangement is another innovation in No. 1 ESS. It permits switching among duplicated common control equipment at electronic speeds. The improved method protects calls that are being processed at the time a switch is made and provides a convenient means for electronically organizing a working system from random combinations of duplicate units; either central control may associate itself with any program store or call store while other units may be in a trouble condition.

In carrying out call processing operations, both of the central controls and their normally associated program stores and call stores simultaneously process the information for the complete call. Interconnections between duplicated portions of the system provide for cross-checking of information. If a mismatch occurs at any point, a fault recognition program is called into play to determine whether the mismatch is due to an error (which does not repeat) or to a true fault. If a fault has occurred in the on-line system, the duplicate equipment immediately takes over

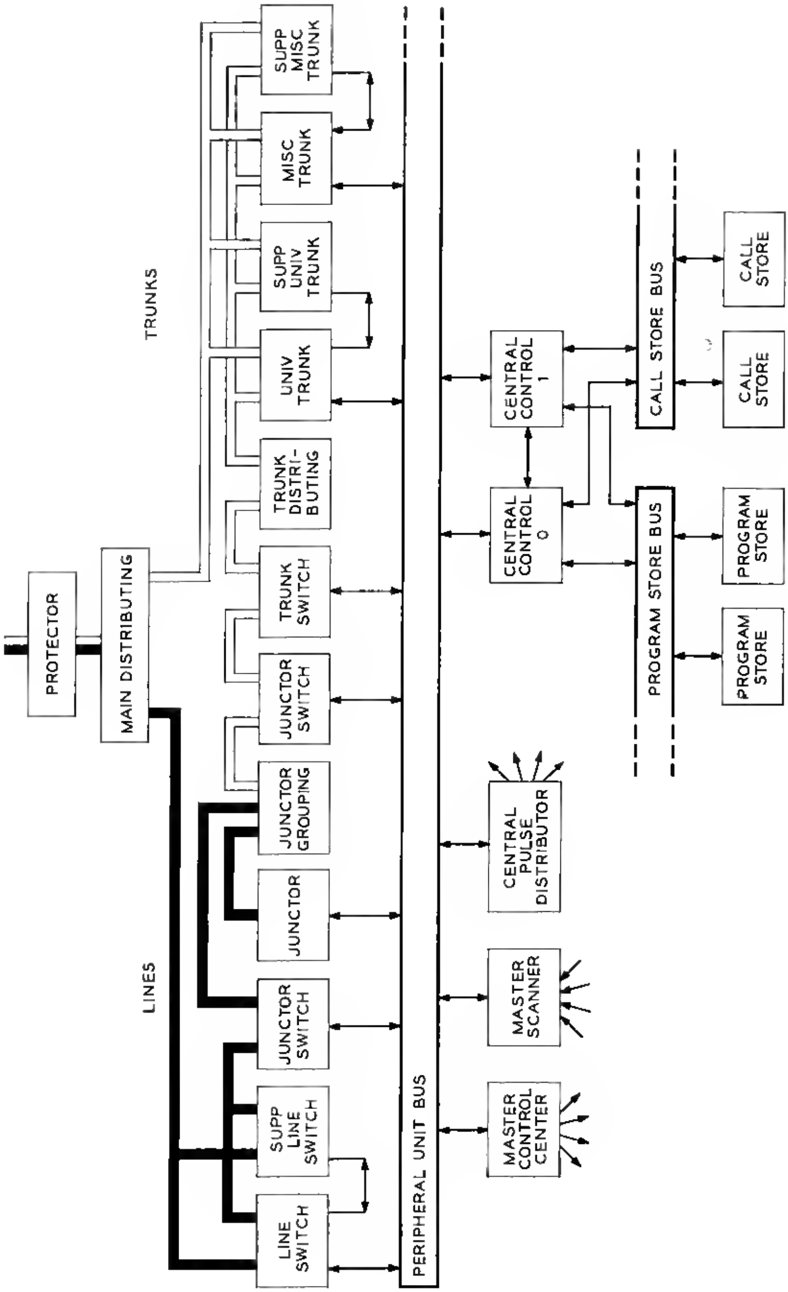

Fig. 10 — No. 1 Electronic Switching System block diagram.

the call processing operations. In its spare time central control carries out a diagnostic routine on the faulty unit. The results of this diagnosis are printed out on a teletypewriter for use by the maintenance man.

In the following sections the design and functions of the major portions described above will be covered in somewhat more detail.

4.4 *Switching Network*

A schematic representation of the eight-stage switching network is shown in Fig. 11. Line link networks, consisting of line switch frames (LSF's) and junctor switch frames (JSF's), contain four switching stages; the remaining four stages are contained in trunk link networks consisting of junctor switch frames and trunk switch frames (TSF's). Wire junctors are used between line link and trunk link networks for line-to-trunk interconnections, and between appearances on the trunk

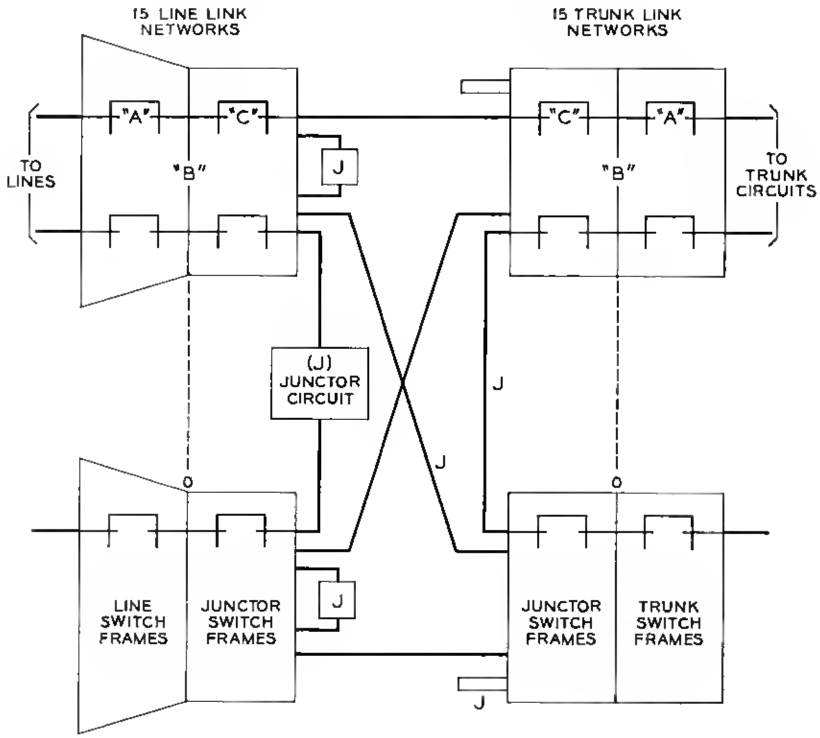

Fig. 11 — Over-all network plan showing line link networks, trunk link networks and typical connections.

link networks for tandem switching. Line-to-line switching is accomplished through a junctor circuit which includes the necessary transmission apparatus and facilities for supervising the individual lines. Because of the wide variety of offices which this electronic switching system is intended to serve, the line link networks are arranged to cover various concentration ratios from 2:1 up to 8:1.

A line switch frame for 4:1 concentration is shown in Fig. 12. The double bay of equipment at the left contains the switching, supervisory and electronic control equipment for interconnecting 512 lines to 128 junctors. A supplementary line switch frame on the right increases this switching capacity to 1024 lines. In this configuration the electronic

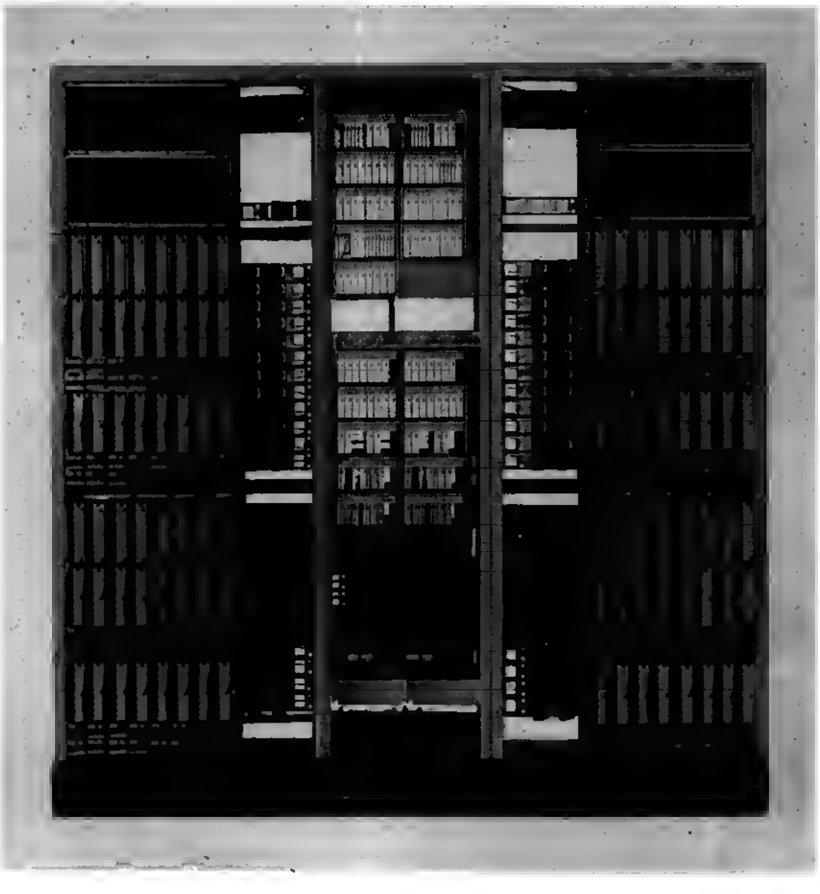

Fig. 12 — No. 1 ESS line switch frames.

network control serves both the basic and supplementary line switch frames.

A number of wire spring relays can be seen on each of these frames. These are used for setting up steering circuits for crosspoint control in the ferreed switches contained in the rectangular cases seen in this Figure. Driving current to operate the ferreed crosspoints is obtained from a solid-state pulser employing a high-power silicon triode. This pulser is located near the bottom of the bay containing the control electronics.

To set up a connection, central control, through the switching frame electronics, orders the establishment of a pulsing path to the appropriate crosspoints. The crosspoints are then closed by applying a high-current pulse through the established network control path.

At the top of the bays in a matrix configuration are "ferrods" which provide line supervision. Both the ferreeds and ferrods were invented especially for No. 1 ESS and are described further below.

4.5 *The Ferreed*[7]

Each of the rectangular ferreed switches shown in the photograph contains an 8×8 array of ferreed crosspoints, as shown in Fig. 13.

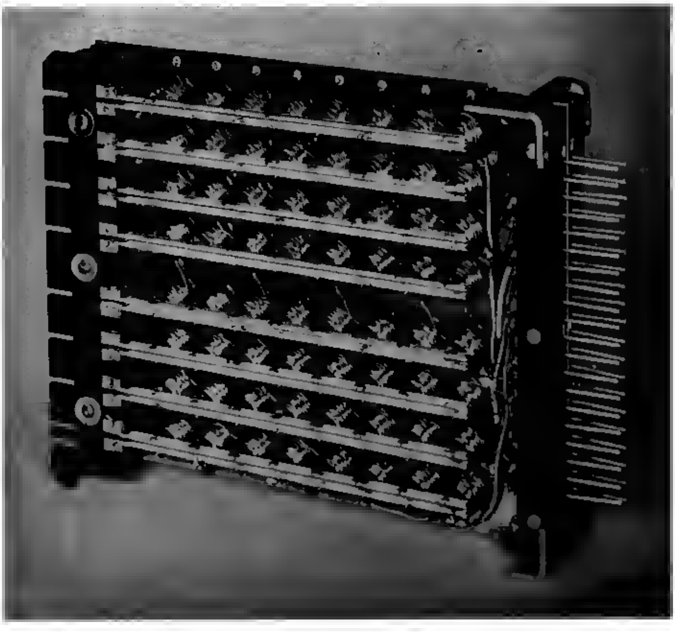

Fig. 13 — No. 1 ESS ferreed switch assembly.

Each crosspoint consists of a pair of dry reed glass-encapsulated switches molded into a small subassembly and inserted with two remendur plates into a solenoid consisting of two control windings as shown by the exploded view in Fig. 14. When a high-current pulse is transmitted simultaneously in the appropriate direction through the two solenoid windings, the remendur plates are poled to produce a north-south magnetic field from top to bottom. Remendur, being a square loop material, remains magnetized after removal of the pulse, causes closure of the reed contacts, and holds them closed without further expenditure of power. Operate current from the pulser flows through appropriate interconnections on the wire spring relays to a given column and row of

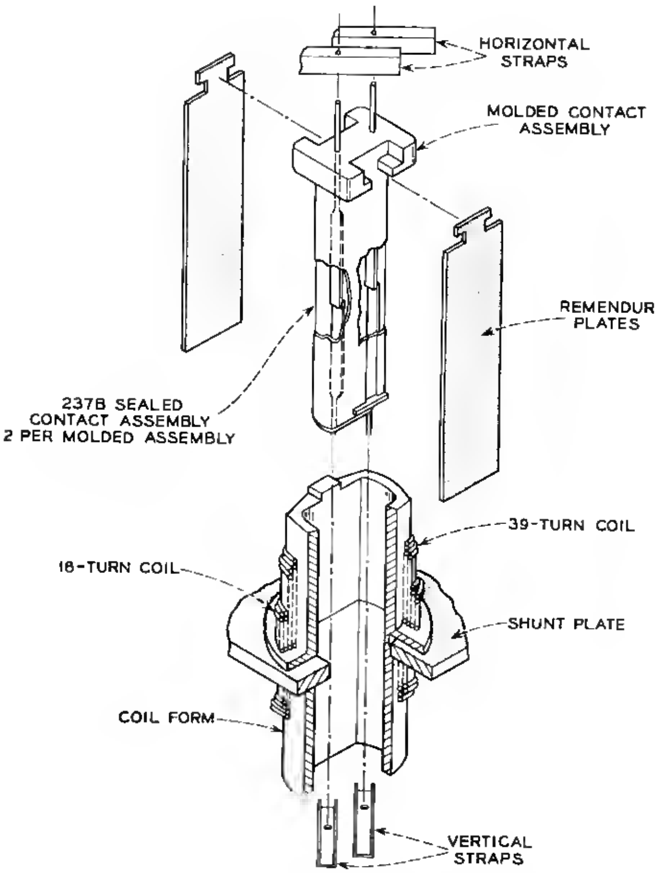

Fig. 14 — Two-wire ferreed crosspoint.

the 8 × 8 ferreed switch unit, thus operating the crosspoint at the intersection of that column and row.

The two windings of the control solenoid are arranged so that a pulse of current through only one of the windings will produce magnetization of the remendur plates in a north-south/south-north distribution about the magnetic shunt plate shown in the diagram. The opposing magnetic fields of the two halves of the remendur plates thus permit the contact to open. This arrangement, together with the matrix interconnection in the 8 × 8 array, produces a crosspoint configuration of the "destructive mark" type. There is no need to release a connection upon completion of a call since the half select current on a subsequent network connection will cause the release of the crosspoint if it is no longer required in the new connection. A network map indicating the closed or open state of the crosspoints is recorded in the temporary memory described later. Thus there is no need for a sleeve lead to be provided in the network as in electromechanical switching systems.

An early model of a machine developed by Western Electric Company for automatically winding the solenoids for the ferreed crosspoints is shown in Fig. 15. Here the entire shunt plate containing the molded assemblies for the crosspoints is oscillated in such a way as to wind four solenoids simultaneously. In the foreground are a two-wire and four-wire ferreed switch assembly before the crosspoints and remendur plates have been inserted.

A second type of ferreed is also required to act as a cut-off relay for ferrod sensors used for line supervision. This design, shown schematically in Fig. 16, may be operated or released by reversing the direction of current through the control winding. When energized in one direction, the remendur rod in the control winding is poled in a direction to aid the magnetic field from a permanent magnet. This causes closure of the reed contact. A pulse of current in the opposite direction switches the remendur field to oppose the permanent magnet to release the contact. The use of this device in connection with line supervision is described below.

4.6 *The Ferrod*

Line supervision is obtained by means of ferrods mentioned earlier. Several varieties of this device are illustrated in Fig. 17. Each of these assemblies contains two ferrods, one at either end of the assembly in a molded wire arrangement that is well adapted to mechanized manufacture using wire spring relay manufacturing techniques. The devices

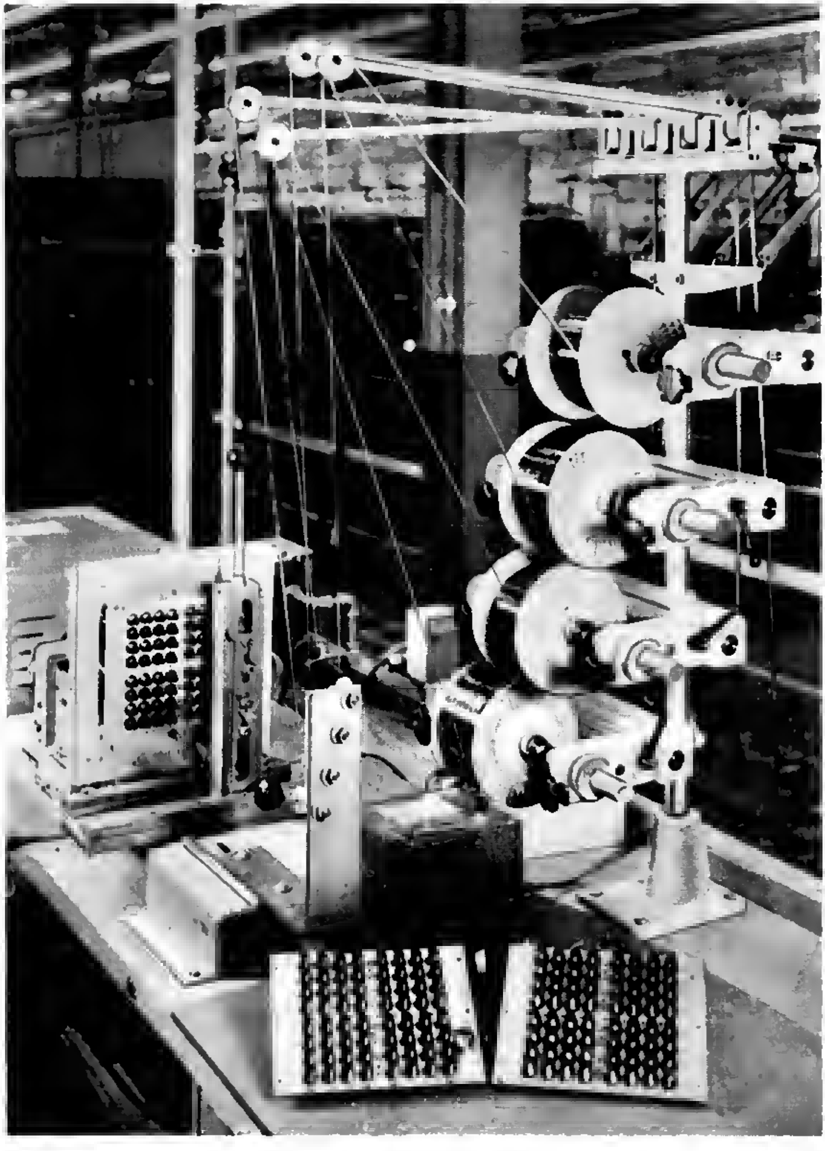

Fig. 15 — Ferreed switch automatic winding machine.

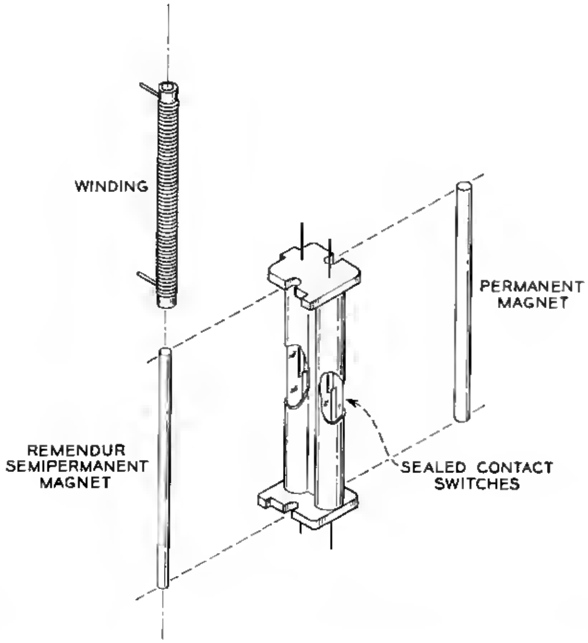

Fig. 16 — Bipolar ferreed assembly.

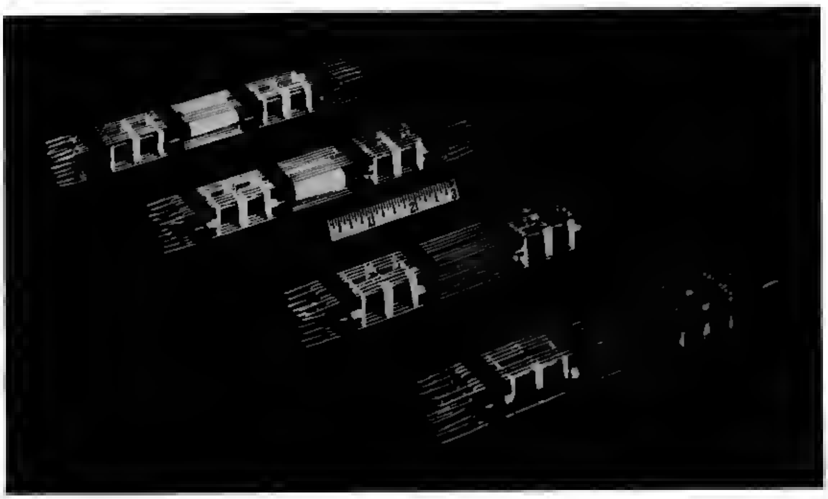

Fig. 17 — Four dual ferrod assemblies.

previously seen in the line switch frames mounted in a matrix configuration were the ends of a number of these dual ferrod assemblies.

A schematic diagram of this simple and reliable device is shown in Fig. 18(top). It consists of a rectangular ferrite stick surrounded by solenoid control windings connected in series with the customer's telephone line and talking battery. In the center of the ferrite stick are two holes through which two small coupling loops are inserted. In the absence of line current, i.e., when the customer is "on-hook," the ferrite stick is unsaturated and good coupling exists between the two single loop windings. Thus a 4-microsecond interrogating pulse transmitted from the scanner to the loop will produce a corresponding pulse in the read-out loop. When the customer goes "off-hook," the resulting cur-

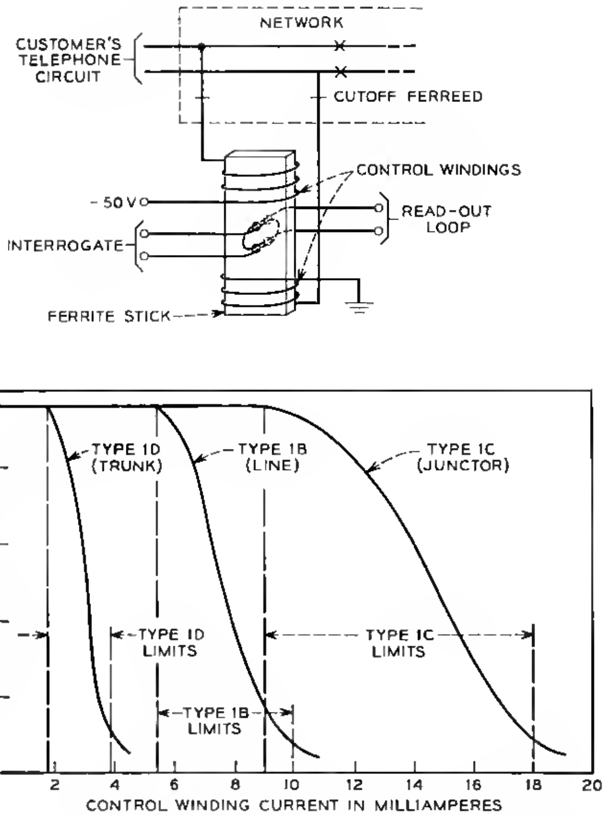

Fig. 18 — Top: ferrod in customer's line circuit; bottom: typical response of ferrods.

rent through the control windings saturates the ferrite stick, with the result that very little coupling exists between the interrogating and read-out loops. Thus it can be seen how this device provides a means for sensing the state of a customer's line at speeds compatible with electronic data processing.

The ferrod control windings are connected to the customer's line via a cut-off ferreed described above. When a service request is detected, an appropriate dial tone connection is set up through the switching network and supervision is transferred to a junctor or trunk circuit. The cut-off ferreed disconnects the ferrod associated with that customer's line to remove any transmission impairment which might otherwise be incurred. The cut-off ferreeds are mounted in a 1 × 8 ferreed switch assembly and may be seen adjacent to the 8 × 8 ferreed switches in Fig. 12.

Ferrods are used not only for customer line supervision but also at various other places throughout the system where high-speed sensing of direct current states is required. The sensitivities needed in these various applications call for three ferrod types, as indicated by the response curves shown in Fig. 18(bottom).

4.7 *Scanner*

Interrogate pulses for the ferrods are obtained from an electronic scanner of 1024 points. The ferrods are arranged in 64 rows of 16 ferrods per row, and the scanner selects one row of 16 ferrods simultaneously when requested to do so by central control. This is accomplished by the arrangement shown schematically in Fig. 19. Half microsecond pulses from the central control address bus are stretched to 4 microseconds and through a ferrite core matrix drive the appropriate row of 16 ferrods. Separate output amplifiers from the ferrod read-out loops supply central control with the "0" or "1" state of the corresponding ferrods through separate output amplifiers.

Fig. 19 also shows some of the features included to sense any malfunction in the scanning processes. One of these shown to the right and labeled ASW check is an "all seems well" pulse. This pulse indicates to central control that a particular row, and only that row, of ferrods was indeed interrogated. Another check feature is shown at the bottom left of the diagram in which a pulse is returned to central control to verify the fact that an "enable" pulse for the scanner was in fact received. Morris experience played a strong role in suggesting these provisions.

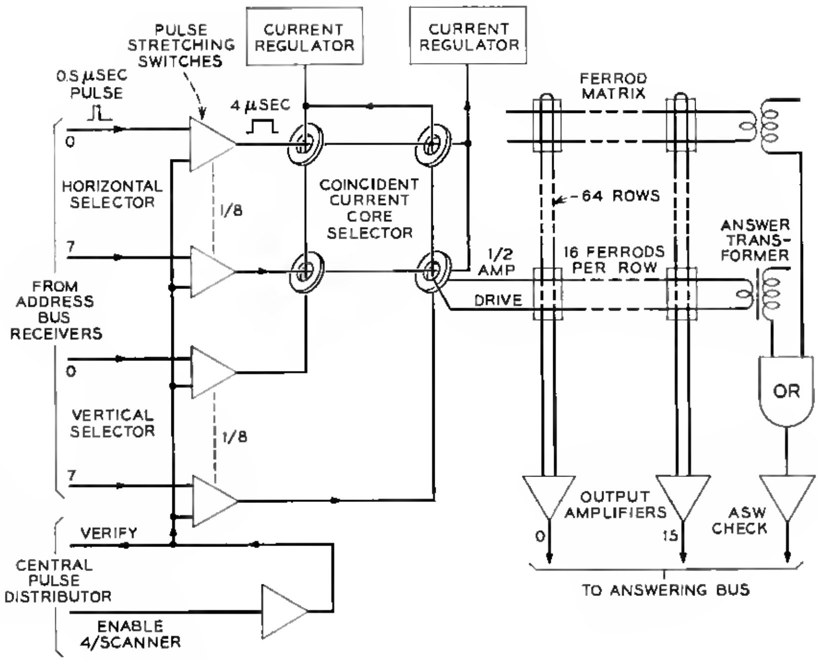

Fig. 19 — Functional diagram of a 1024 point scanner.

4.8 *Trunk Circuits*

Earlier it was mentioned that stored program control permits a major simplification in trunk circuits. Through this type of operation, it has been possible to reduce drastically the number of different types of trunk circuits required and to provide many of them on a plug-in basis with standardized factory wired frames for the receptacles. Compartments for plugging in the trunk circuits are shown in the universal trunk frame illustrated in Fig. 20. Each compartment accepts a trunk package containing two trunk circuits of a type indicated schematically in Fig. 21. From the notes on the diagram, the reader will observe the wide variety of circuit configurations made possible with program control. Other trunk circuits of this same general type are provided to meet special needs for interconnection with existing electromechanical offices. Some of these incorporate special networks to improve return loss.

A miscellaneous variety of trunk or service circuits are also required

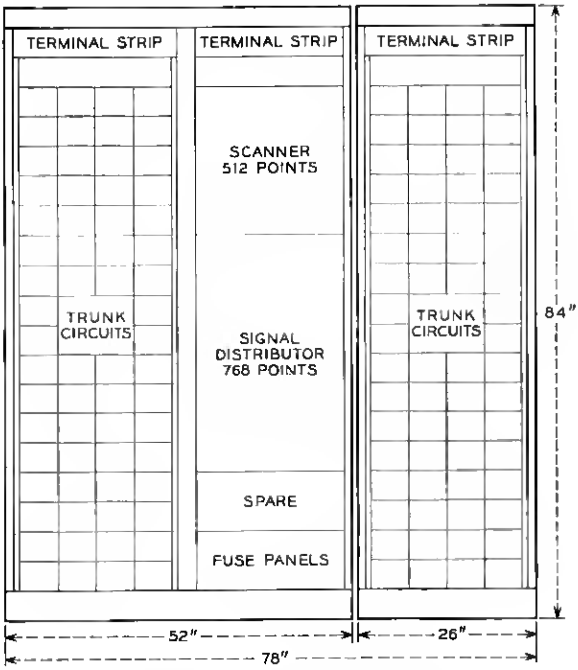

Fig. 20 — Universal trunk frame.

to provide such functions as dial tone, ring, audible ring, TOUCH-TONE receivers, and the like. These are mounted in a miscellaneous trunk frame as required and are permanently wired at the factory.

4.9 *Central Control*

Central control is the heart of the high-speed information processing common control equipment. It is a high-speed semiconductor logic machine designed to interpret instructions contained in the program store and to carry out the appropriate logical operations contained in each instruction. A photograph of one of the two central controls used in the system is shown in Fig. 22. Each central control is made up of approximately 2300 circuit packages containing approximately 14,000 transistors and 45,000 diodes. Typical plug-in packages and the nest into which they are plugged are shown in Fig. 23. Considerable development effort was devoted to the design of a highly reliable connector which could be manufactured at low cost. This was essential in view of the large number of plug-in packages used in the system.

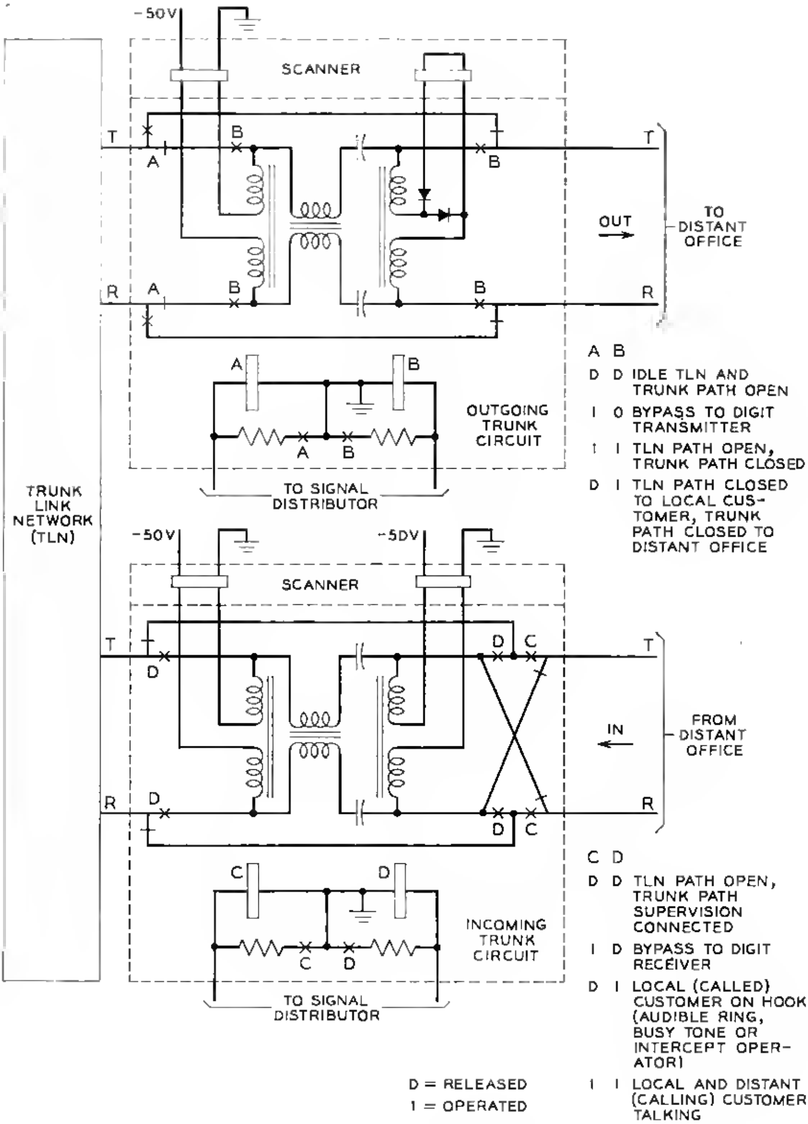

Fig. 21 — Simplified No. 1 ESS trunk circuits.

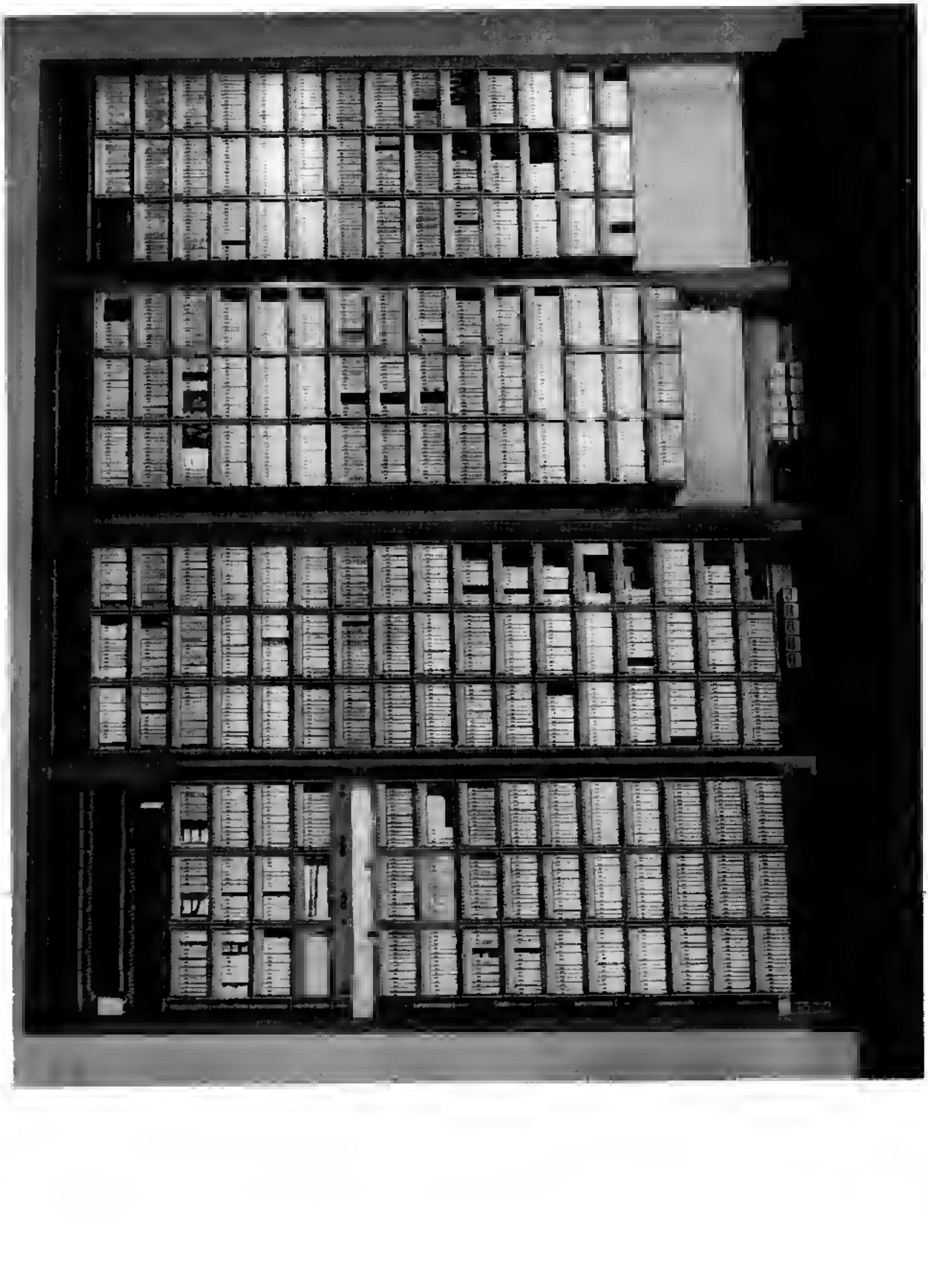

Fig. 22 — No. 1 ESS central control.

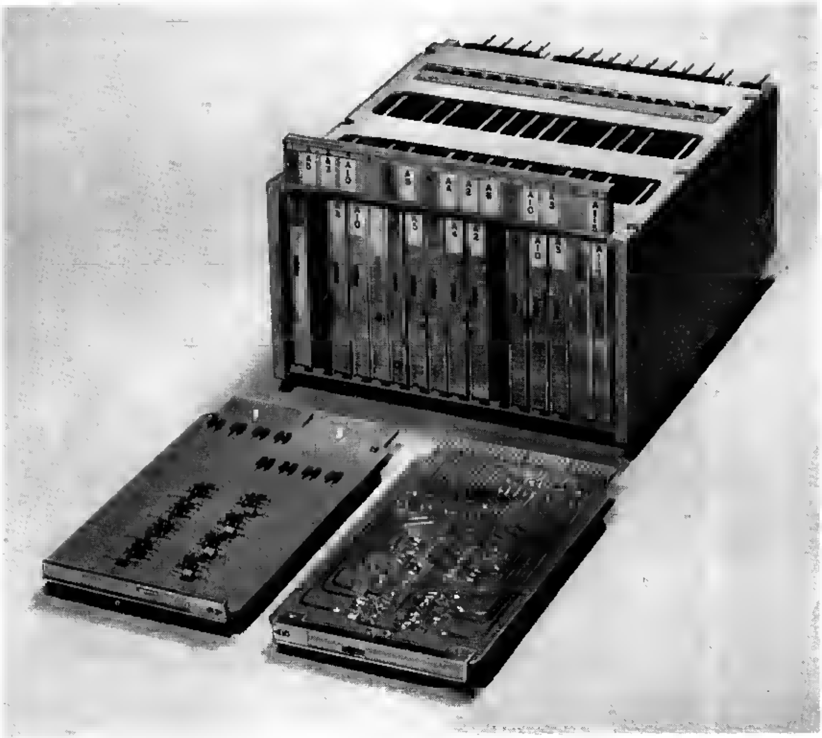

Fig. 23 — No. 1 ESS logic packages and nest.

Central control is word-organized to receive 44-bit instructions from the program store and to process information with the aid of the call store on a 24-bit word basis. Its cycle time is 5.5 microseconds.

A considerably simplified block diagram of central control is shown in Fig. 24. No attempt will be made here to describe this diagram. Instead, the types of actions the central control is designed to perform will be outlined briefly. The organization differs from that of a general purpose computer since the functions required in a telephone switching office are primarily logical rather than arithmetic operations.

A special program language with appropriate symbolic codes was evolved to optimize the performance of the system in processing information for telephone switching type operations. Each word in the program store shown at the top of the diagram is identified by a specific address designated in binary code. The program word located at that address contains an operation order, information as to where the data

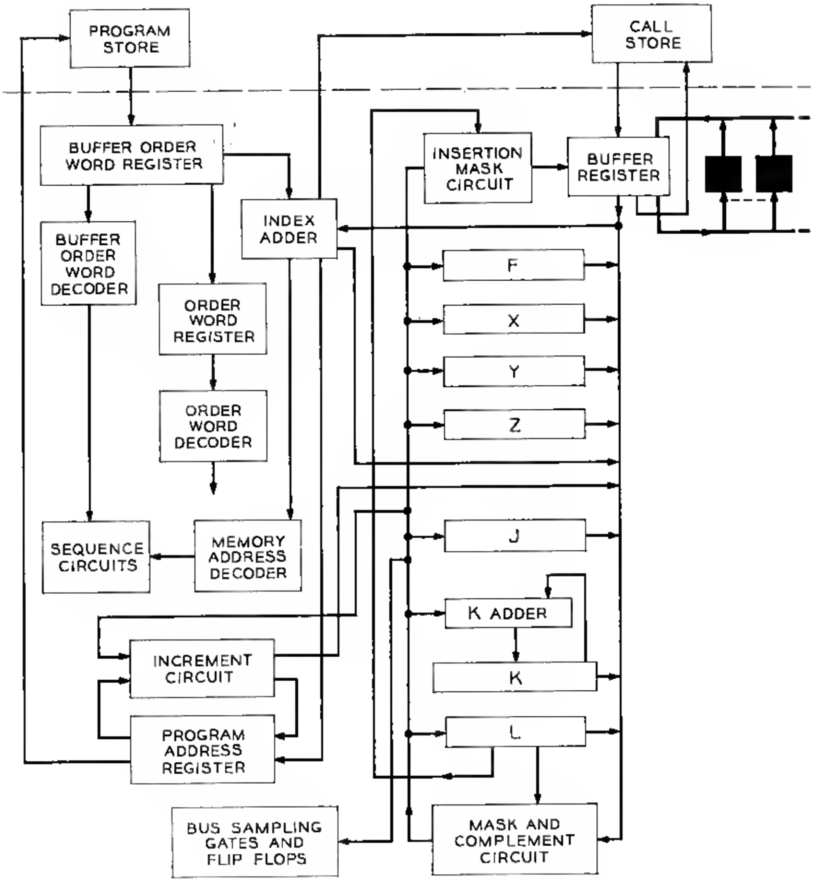

Fig. 24 — No. 1 ESS central control — simplified block diagram.

to be processed may be found in memory, and various other symbols which may request such operations as masking a portion of a word, complementing the word to be processed, or performing the logical union or product with another word. Various types of operation codes are included in the programming language. The class of operation code, an example of the symbology used, and the meaning of that symbology for several types of operation are shown in Fig. 25. The logic design of central control provides for interpreting these types of instructions and for carrying out the specified operation.

A frequently used order related to the "shift" order shown in the

CLASS	EXAMPLE	MEANING	NUMBER OF TYPES
MOVE	MK	MEMORY TO ACCUMULATOR (K)	28
ADD	AWK	ADD WORD TO K	11
SUBTRACT	SBR	SUBTRACT BUFFER FROM REGISTER	10
COMPARE	CMK	COMPARE MEMORY WITH K	5
LOGICAL	PMK	PRODUCT OF MEMORY WITH K ("AND")	24
	UWX	UNION OF WORD WITH REG ("OR")	
	H	SHIFT	
TRANSFER	TKAZ	TRANSFER IF K IS ZERO	26
COMBINED	TZRFZ	TRANSFER IF K IS ZERO, IF NOT FIND FIRST ONE AND ZERO IT AND SAVE BIT POSITION IN F REGISTER	12
	QMX	ROTATE K, MOVE MEMORY TO X REGISTER	66

Fig. 25 — Example of operation codes.

figure is called "rotate." This is similar to a shift order except that the bits of a word which might be shifted off the right-hand end of the register are saved by bringing them back to the left end of the register. For example, this instruction may be used to determine the "right-most one" in a binary word. Suppose that the bits of this word represent the busy ("0") or idle ("1") state of a group of trunks. The single order to determine the "right-most '1' " would immediately locate the first idle trunk.

In addition to logic circuitry to carry out operations of the types described above, central control includes a number of features provided for automatic maintenance purposes. These are listed in Table I.

4.10 *Program Store*

In Morris the program store was the flying spot store as already noted. For the commercial system, it was deemed desirable to eliminate electron tubes wherever possible, both from a reliability point of view and to simplify power supply arrangements. Fortunately, the twistor memory,[8] invented at Bell Laboratories, appeared on the scene early enough for this purpose.

An over-all view of the program store incorporating sixteen twistor modules together with access and read-out electronics is shown in Fig. 26. This store, of which at least two are provided in each office, provides a memory capacity of about 5.8 million bits organized into 131,000 words of 44 bits each. Any word in the store may be randomly accessed

Table I — Central Control Maintenance Facilities

1. Internally and externally generated maintenance interrupts.
2. Information in call store encoded with a parity bit checking both data and address.
3. Information in program store stored in Hamming code, the parity bit checking both address and data; can correct single errors, detect double errors in data, can detect single and double errors in address.
4. Program and call store reread facilities.
5. Round trip check of central pulse distributor enables output to peripheral units.
6. An internal check signal ("all seems well") is generated in program stores, call stores, and scanners; absence is detected by central control.
7. Synchronizing signal on all store communications.
8. Word matching between central controls of selected and selectable internal central control points:
   a. all call store communications normally matched,
   b. program store replies matched after a transfer,
   c. selected matching of busses, program store address register, and key decoder and sequence circuit outputs.
9. Error counters.
10. Emergency action circuit.
11. Off-line operation possible for selected system configurations.

by request from central control. The 44 bits in each word consist of 37 information bits, a 6-bit Hamming code for single error correction-double error detection, and a final over-all parity bit. The error detection and correction code is computed across not only the word of information to be read out of memory but also its address.

The vertical slots which may be seen in the twistor modules are designed to receive aluminum cards such as that shown in Fig. 27. Each of the cards has 64 columns of vicalloy spots arranged in 45 rows. Forty-four rows are used to store the 44 bits of a program word. The 45th bit, together with a row of elongated magnets shown on the upper edge of the card, serve to condition the magnetic properties of the twistor wire as the card is inserted. One hundred twenty-eight cards are used in each of the twistor modules, thus providing a storage capacity of 8196 44-bit words per module.

Of the 16 modules in the program store, 13 are allotted to program and the remaining 3 to translation information. Approximately half of the program is devoted to telephone call processing and administrative operations, and half is devoted to fault recognition and diagnostic programs designed to ensure dependability and simplify office maintenance.

The modules devoted to translation contain such information as line-to-directory number translation, class of service marks, trunk translation, abbreviated dialing lists, and the like. Approximately 16 types of translation information are used, and class of service designations are

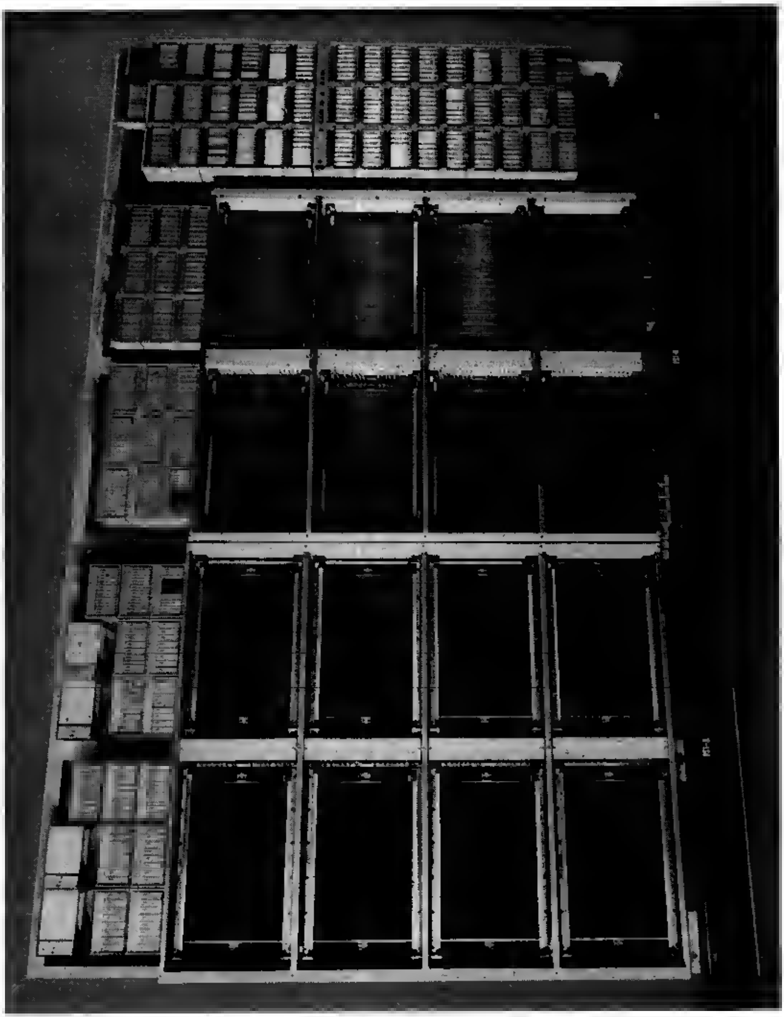

Fig. 26 — No. 1 ESS program store.

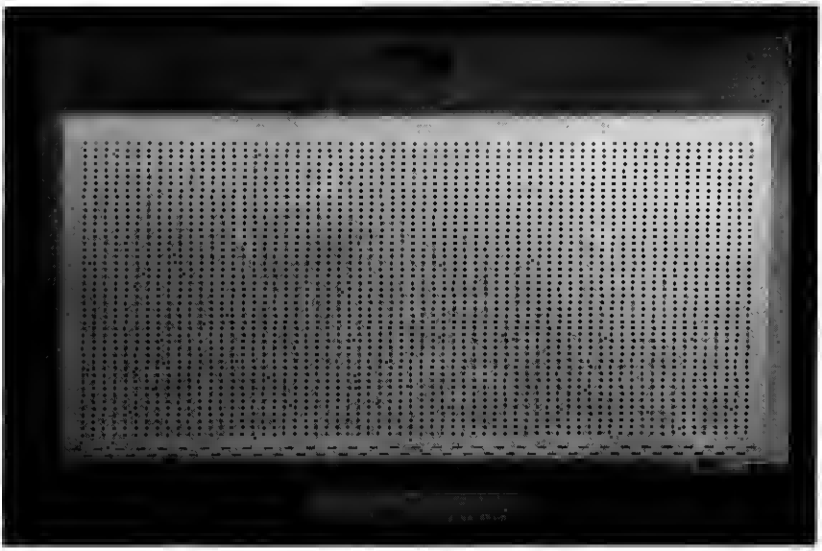

Fig. 27 — Magnet card for twistor store.

practically limitless within the capacity of the store. On the average, approximately three words of program store are required per line. Thus, the three modules provide translation for an office of about 8,000 lines. For larger offices, additional program stores would be required to provide additional translation capacity.

An understanding of the operation of the twistor may be obtained with the aid of Fig. 28. Forty-four pairs of copper read-out wires (of which four pairs are shown in the diagram) run adjacent to the vicalloy spots on the magnet card; each pair forms a balanced transmission line feeding a sensing amplifier. At each word position a single-turn coupling loop is disposed at right angles to the 44 pairs of twistor wires. A pulse can be driven through this loop by switching a ferrite core accessed by appropriate X and Y currents. One wire of each of the 44 pairs is surrounded by a spiral of permalloy tape. The vicalloy spots on the magnet card are located at the intersections of the twistor wire and the single-turn interrogating loop. In the absence of a magnet at that intersection, an access pulse in the interrogating loop switches the permalloy twistor wire and produces an output at the end of that wire. However, a permanent magnet at that intersection will prevent the permalloy tape from switching, with the result that substantially no output is obtained. Thus, the vicalloy spots on the magnet cards can be used to define the "0's"

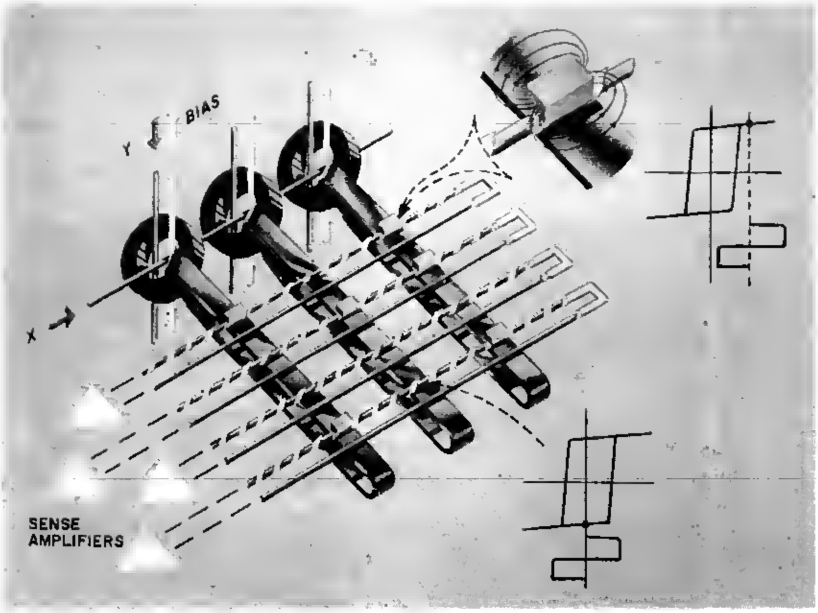

Fig. 28 — Principles of permanent magnet twistor.

and "1's" of a 44-bit word by either magnetizing or demagnetizing the tiny vicalloy magnetic material.

The 44 pairs of twistor wires are encapsulated in a plastic tape which is cemented in a continuous run to the vertical supporting members of the twistor module. This may be understood more clearly from Fig. 29, which shows an early version of a machine designed by Western Electric for fabricating twistor modules. A rear view of a completed module showing the access core matrix is shown in Fig. 30.

4.11 *Memory Card Writer*

It should be evident that either the program or translation information can be modified by simply changing the pattern of magnetic spots on the removable magnet cards. This permits a great deal of flexibility in office administration, not only in modifying translation but also in providing new service features. For these types of changes, no hardware or wiring modifications are required and service changes can be made in a minimum of time.

Changes in the magnetic bit pattern can be made with the aid of a

Fig. 29 — Twistor module assembly operation in Western Electric Company plant.

memory card writer, shown in Fig. 31. All of the cards in one twistor module are removed by a motorized program store card loader shown mounted vertically on the card writer. The card writer is arranged to withdraw one card at a time from this card loader and pass a 44-bit writing head across its surface. The card is then automatically replaced

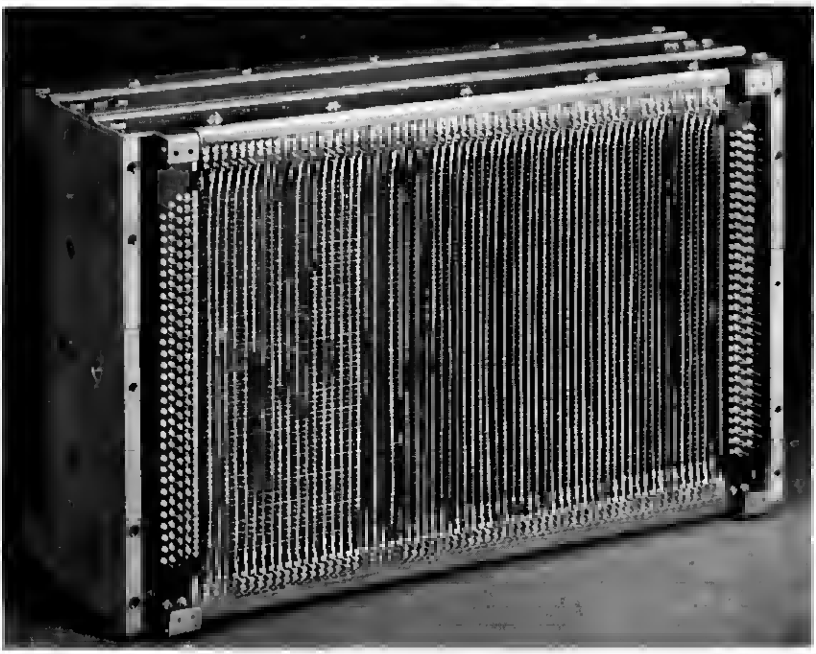

Fig. 30 — Twistor module access matrix.

in the loader, and the unit is indexed upward to place the next card into position for withdrawal.

The appropriate information for the 44 bits on the writing head can be obtained from a tape reader for initial magnetization of the cards at the factory, or from the call store via central control in an operating office. In the latter case, information is inserted into the switching system via the maintenance teletypewriter into a "recent change" space in the call store. Before this space is completely full, the temporary translation information can be automatically transferred to the twistor memory in the program store via the card writer as outlined above.

By arranging to use the call store as a temporary repository for change information, it is possible to respond very rapidly to customer requests for a change of service. For example, a remote teletypewriter can be provided to a service order clerk who can type information (such as abbreviated dialing lists) directly into the system. Service can be activated as soon as the service order clerk has finished typing the information. In processing telephone calls, central control examines the "recent change" space of the call store before referring to the program store

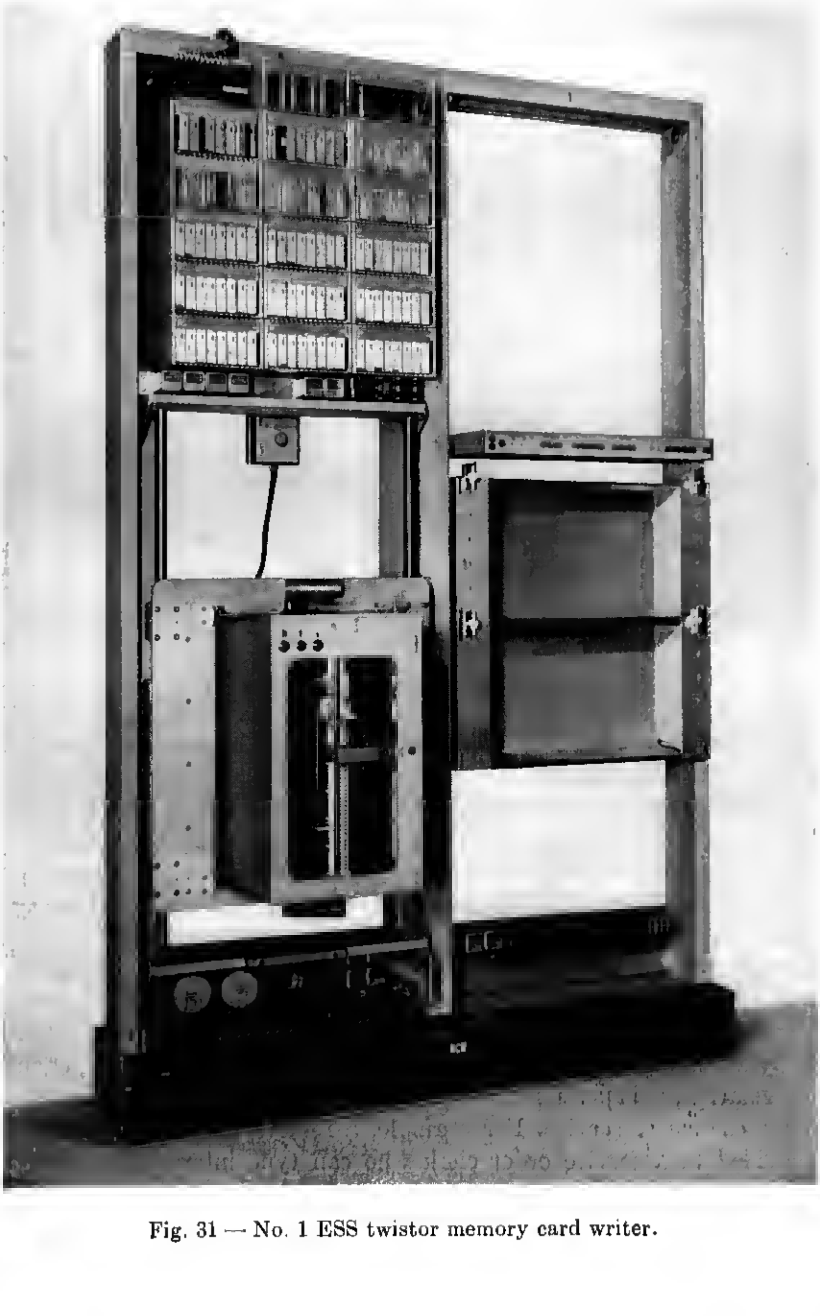

Fig. 31 — No. 1 ESS twistor memory card writer.

translation tables. It is expected that clearing of the "recent change" space and transferring the information to the program store will be required no more than once a week, even in a fairly active office.

4.12 *Call Store*

Reasons similar to those given for replacing the Morris flying spot store with the twistor store led also to replacement of the Morris barrier grid store by a solid-state temporary memory. For this purpose the ferrite sheet was chosen as the memory element.

A single ferrite sheet is shown in Fig. 32. This sheet contains an array of 256 holes on a 16 × 16 grid, each of which acts as an individual ferrite core. The difficult threading operation common to a ferrite core matrix is largely overcome by the technique of plating one of the leads in a continuous path through the holes in the ferrite sheet. A number of these sheets can then be stacked to provide the memory capacity required and the additional wiring added in a relatively simple operation. This is indicated schematically in Fig. 33, and a completed memory module having capacity of 2,048 words of 24 bits each is shown in Fig. 34.

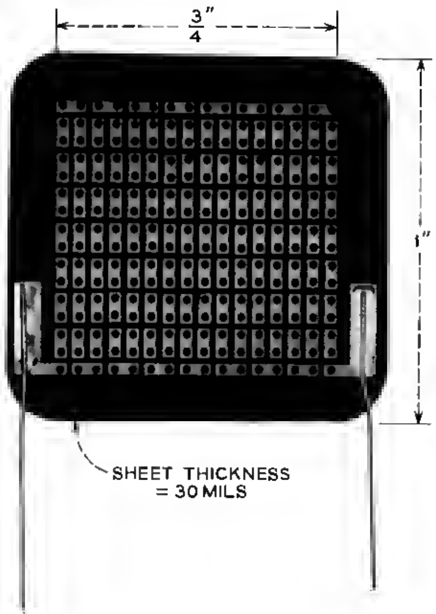

Fig. 32 — Ferrite sheet for No. 1 ESS temporary memory.

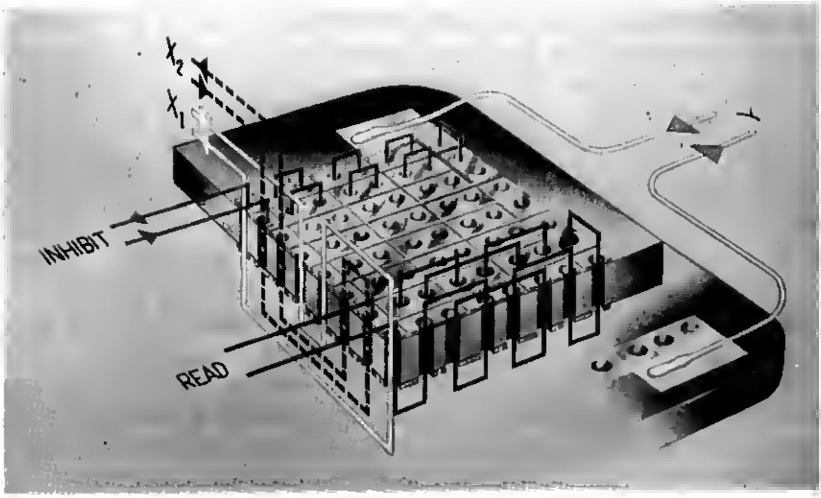

Fig. 33 — Access wiring for ferrite sheet memory.

As indicated in the caption for this figure, four such modules are used in each call store. They are mounted behind the blank panel shown in the photograph of a call store, illustrated in Fig. 35. The electronic packages associated with call store operation may also be seen in this photograph.

The number of call stores required in a particular office varies with size and traffic but will never be less than two for the smallest office because of the duplication requirement.

4.13 *Master Control Center*

The interface between man and machine in No. 1 ESS is the master control center, two portions of which are shown in Figs. 36 and 37. The alarm and display section on the right-hand panel of Fig. 36 indicates which of the duplicated common control units are currently in charge of the office as well as the condition of the off-line units. As already noted, switching between these units is normally made under automatic control of the system. However, push buttons provide for manual intervention. On the test panel at the left are various keys and lamp indications from which line-load control can be exercised under unusual traffic conditions. Facilities are also provided for performing certain system tests.

The main interface with the machine is the teletypewriter shown in

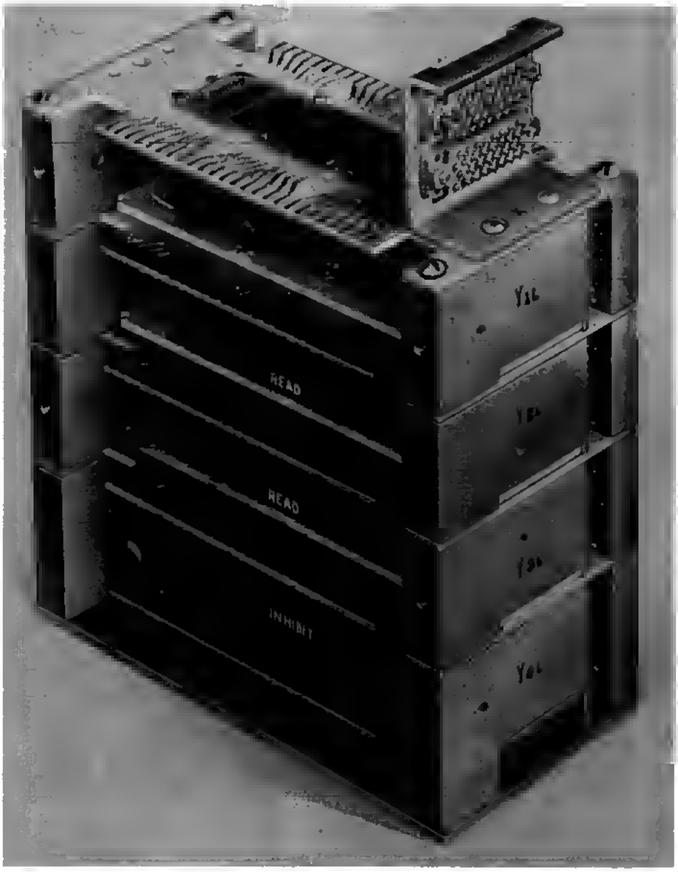

Fig. 34 — The No. 1 ESS ferrite sheet module has a capability of 2048 words of 24 bits each or a total of 49,152 bits. Four such modules are used in each call store.

Fig. 37. It can be used by the operating personnel to request the machine to perform a variety of functions and is also used to print out messages which the machine wishes to give to the maintenance man. Examples of the former are the use of the teletypewriter to update translation information or to insert special service changes such as customer abbreviated dialing lists. The teletypewriter may also be used to request a print-out of traffic data or to perform certain maintenance test sequences.

Under normal circumstances, it is anticipated that No. 1 ESS offices will be unattended. Provisions are therefore made for operation with remote teletypewriters. One might be provided for the service order

Fig. 35 — No. 1 ESS call store.

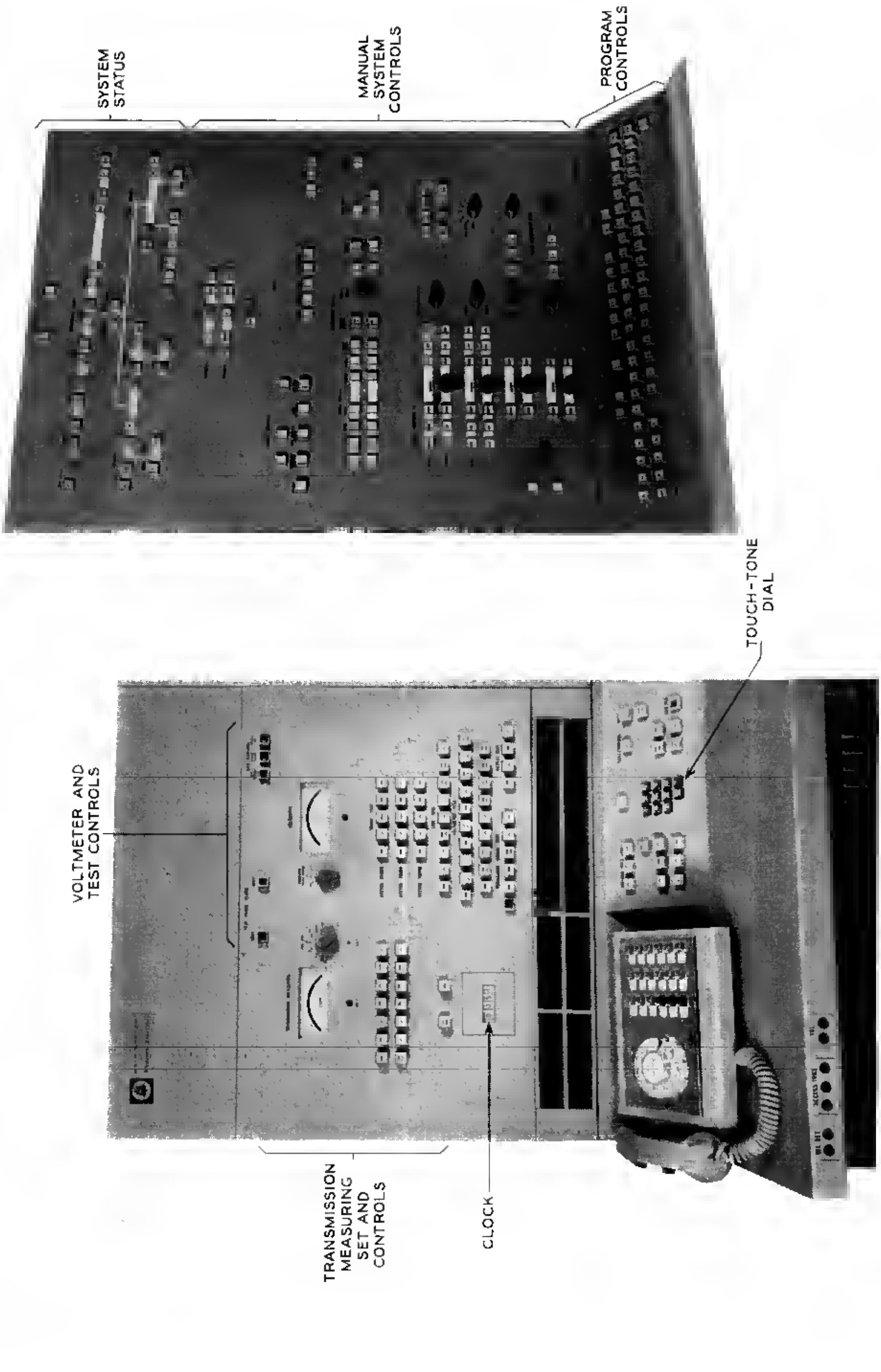

Fig. 36 — No. 1 ESS master control center — test panel and alarm and display section.

Fig. 37 — No. 1 ESS master control center — TTY and AMA recording.

clerk while another could be located in an attended office where a maintenance man would have access to maintenance information generated at the unattended office.

Next to the teletypewriter in Fig. 37 are two magnetic tape recorders used to record information for automatic message accounting. These are "write only" recorders and operate only when sufficient information has been accumulated in the call store to justify recorder operation. Information on the magnetic tape is recorded in blocks and in a format suitable for processing in a centralized message accounting center. Two recorders are provided for redundancy as well as to permit tape changes without interrupting recording operation.

The remaining portion of the administration center is the twistor magnet card writer, described earlier in connection with Fig. 31.

4.14 *Size and Power Requirements*

In the design of No. 1 ESS, the height of frames was limited to 7 feet rather than the 11-foot, 6-inch height generally found in electromechanical offices. This height eases the maintenance problem and also permits installation in conventional ceiling-height buildings. In spite of the reduced frame height, the floor space requirements are less than one-half the floor space required for an equivalent No. 5 crossbar office.

No. 1 ESS derives its power from +24-volt and −48-volt storage battery plants continuously charged from commercial power with diesel engine generator back-up. Circuits are designed to operate over the full discharge range of the batteries, and there is no requirement for end-cells or counter-cells. A standard ringing generator is used with programmed selection of ringing phase to provide immediate ring on customer lines.

Various tones required in the system, such as dial tone, audible ring, high and low tones, re-order tone and the like, are supplied by solid-state oscillators with electromechanical interruption at the appropriate rates. These tones are made available to the system from a balanced terminated impedance to avoid transmission impairment during tone application.

4.15 *Programming*

The collection of equipment frames comprising a No. 1 ESS office cannot process a single telephone call without the program which defines the myriad steps required to carry out the appropriate system operations. As already noted, this program for a typical office will contain 100,000

or more 44-bit words for telephone operating and maintenance routines and perhaps 30,000 words of translation information. The problem of writing this program is a major one indeed and occupies the time of a large staff of engineers and programmers.

A major part of the programming activity is devoted to defining the various features which the office is intended to provide. A second portion of the problem is to convert this design information into the symbolic language developed for No. 1 ESS and to process the resulting symbolic program into a form suitable for use by the memory card writer. A third and important activity is the testing of these programs on the actual No. 1 ESS to locate and correct errors which may occur during the first two steps.

To simplify and expedite the conversion of symbolic programs into binary information on a magnetic tape for the card writer, a special compiler program has been written. This compiler, known as PROCESS III,* is designed for use with an IBM 7094 scientific computer. It converts symbolic information (punched onto cards) into binary words to which the compiler automatically assigns absolute memory addresses for use in the twistor store. The compiler also supplies a binary tape which can be run with a simulation program in the general-purpose computer for initial program "debugging." A schematic representation of the flow of information in this process is given in Fig. 38.

The program supplied with each central office must uniquely define both the service features to be provided by that office and a programmed definition of the hardware available in that office. In the latter category, for example, would be a programming statement of the number of originating registers in call store, number and types of trunks available to the office, network concentration ratio, etc. However, the preparation of a complete specialized program for each Central Office would be impractical. Fortunately, many of the operating and maintenance characteristics are common to a large class of offices, and only a small part of the program need be produced uniquely for each office. The common portion of the program has been called the generic program. This includes the maintenance program suitable for all offices of the class and the operating program, which includes all service features and operating characteristics anticipated for offices of that class. A small portion of the program, called a "parameter table" is specially prepared to meet the operating company requirements for the individual office. With the use of general-purpose computers to mechanize the conversion of operating

* *PRO*gram for *C*ompiling *ESS*.

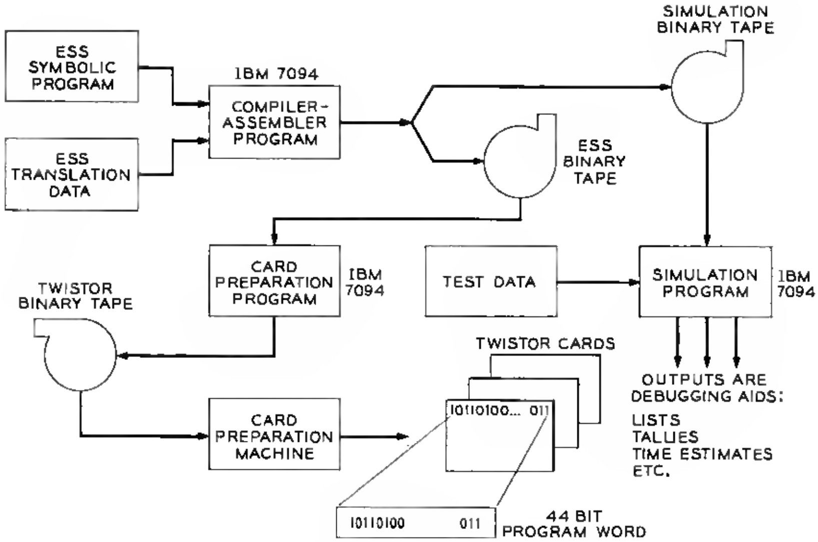

Fig. 38 — No. 1 ESS program information processing.

company requirements into specific office programs, it is possible to generate the twistor information for each office in a very short time.

Special programs are also provided for the twistor memory to serve as both a laboratory tool and by Western Electric Company installation crews. These are called "X-ray programs." When inserted in the program store, they are used to exercise the No. 1 ESS circuits to insure that all installation interconnections have been properly made and to locate any troubles which may have occurred as a result of shipping damage.

V. PROGRESS IN PRODUCTION

During the development of No. 1 ESS, close liaison was maintained with engineers of the Western Electric Company to take advantage of their production experience in the initial designs. This close collaboration resulted in apparatus and equipment designs compatible with high-volume, low-cost manufacture. It also permitted Western Electric to develop special production machines during the development interval. As a result, production systems were available at a much earlier date than would have been possible otherwise.

The Western Electric Company's plant at Columbus, Ohio, produced the first No. 1 ESS during 1962 to serve as a test model at Bell Telephone Laboratories, Holmdel, New Jersey. The frames for the first

commercial office at Succasunna, New Jersey, were produced in 1963 and by the end of 1964 some 1470 frames had been shipped by Columbus for installation at nine more central office locations. Five of these were equipped with four-wire switching networks to serve military users.

The production rate at Columbus will increase rapidly during 1965, and deliveries will also be made from Western's Hawthorne Works in Chicago to meet the rapidly growing demand for this new system. Within the next eight years the combined output of the two Western Electric plants is expected to reach a level of 3,000,000 lines per year.

Several views of early manufacturing operations at Columbus are shown in Figs. 39, 40, and 41.

VI. NO. 101 ESS[9,10,11,12]

6.1 *Design Considerations*

No. 1 ESS will provide modern switching services not only to residence telephones but also to the business community. However, it will be many years before the existing electromechanical switching plant will be superseded by this new central office system. In the meantime, it

Fig. 39 — Western Electric Company manufacturing operations: monorail area — frame testing.

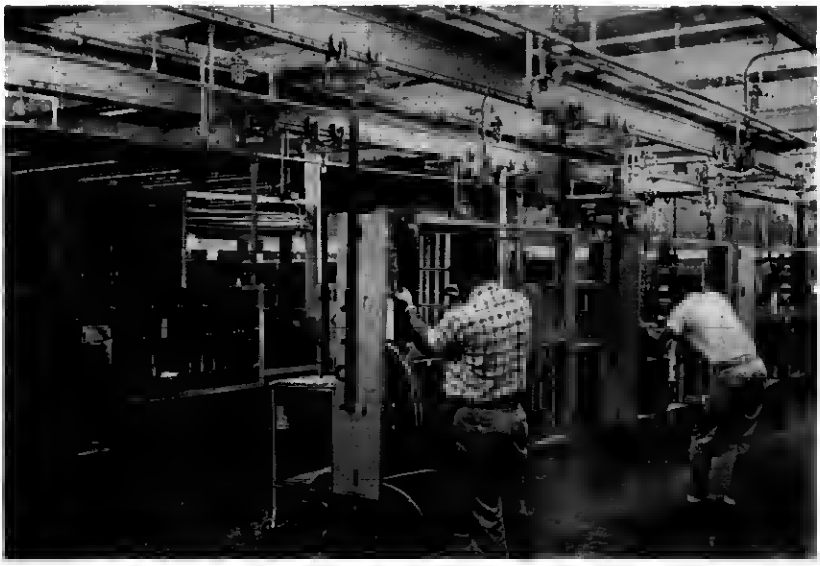

Fig. 40 — Western Electric Company manufacturing operations: monorail area — frame assembly and wiring.

Fig. 41 — Western Electric Company manufacturing operations: unit surface wiring.

seemed appropriate to provide business customers with the new services, made economically attractive with electronics, by supplementing the standard electromechanical central office equipment. No. 101 ESS was designed to fill this need.

An analysis of PBX customers being served by the Bell System indicated that some 80 per cent of existing electromechanical PBX's serve less than 200 extensions. As an initial offering, it was therefore decided to develop the system in this size range. It was also decided that the attractive features of stored program control already discussed in connection with No. 1 ESS should be provided with the PBX design.

It turns out, however, that stored program control systems are currently economical only in large sizes — much larger than the 200-line capacity envisioned for initial service. This led to a concept in which a stored program group control located in the central office would serve a number of outlying PBX switch units on the business customers' premises. This is the concept used in No. 101 ESS. It has the further advantage that most of the maintenance and administration activity for the several PBX's can be performed in the central office, thus reducing servicing costs.

In No. 101 ESS, switching at the customer's premises is performed by the use of a time-division switching network. One of the considerations which led to the choice of time division for this application was a desire to minimize floor space requirements at the customer location. A second consideration was that a time-division switch operates silently and can be installed in any available space without considering acoustic noise interference to customer activities. To minimize installation time on the customer's premises, the switching unit is contained in a single cabinet provided with plug-in connectors.

6.2 *System Organization*

Fig. 42 illustrates the system plan chosen on the basis of the considerations outlined above. A group control unit of the stored program variety is located in the central office building near the electromechanical central office with which it is to be associated. Central office trunks and control data links interconnect this group control to outlying time-division switch units located on the premises of a number of business customers. In this system the group control is designed to handle a maximum of 3200 extensions divided among as many as thirty-two switch units. The maximum capacity of each switch unit in this first offering is 200 lines although larger switch units are under development. By sharing the

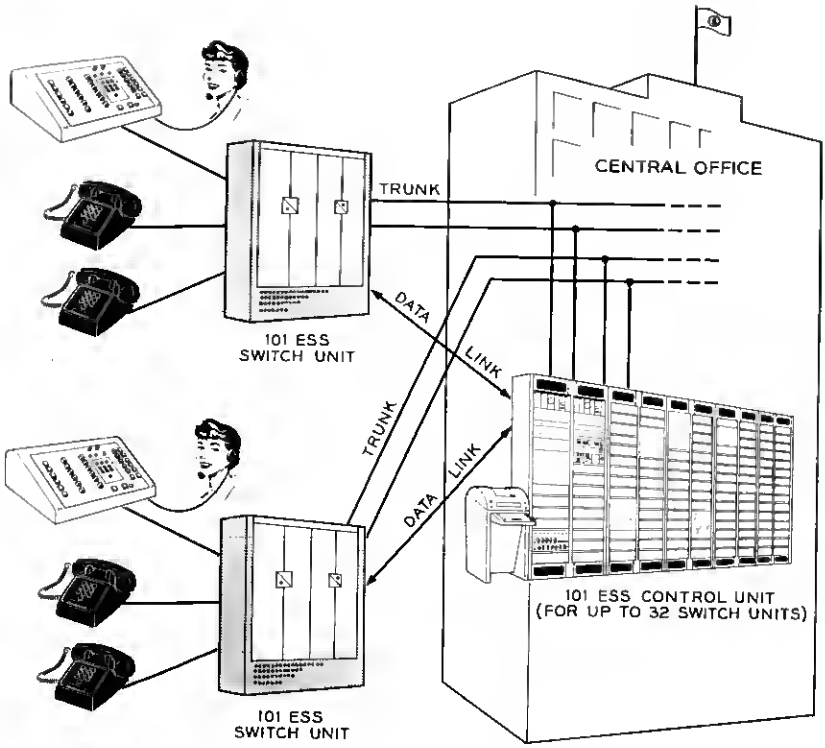

Fig. 42 — 101 Electronic Switching System.

control among a number of business customers, the advantages of stored program flexibility can be obtained economically.

The trunks shown on Fig. 42 between the switch unit and central office provide access between the PBX and the Bell System network for outgoing and incoming calls. Connections shown between those trunks and the control unit are for trunk seizure and control only, and do not provide a voice-frequency transmission path.

The data links shown between the switch unit and control unit are of two types. One is a 4-wire, two-way data link for interchange of digital control information, and the second provides a transmission path for dialed or TOUCH-TONE digits. The data links are ordinary voice-frequency pairs and provide for a data transmission rate of about 750 bits per second. There is no technical limit to the distance between switch units and control unit.

A simplified block diagram of an individual switch unit is shown in Fig. 43. All extensions and trunks to the central office are multipled through electronic gates to two time-division highways or busses. Each of these busses is equipped with its own memory and control to provide system redundancy. The use of two busses doubles the number of time slots available to the customers, provides redundancy in the case of bus failure, and makes possible a very convenient means for establishing conference calls.

6.3 *Group Control*

A photograph of the group control unit is shown in Fig. 44. The four center bays in this equipment line-up contain two stored program call processing units which are essentially mirror images of each other. The system program is contained in the twistor memory module mounted in the lower portion of the frames. A third twistor memory module in one of the frames stores line information, abbreviated dialing lists, class of service marks, and the like. This store is not duplicated since its

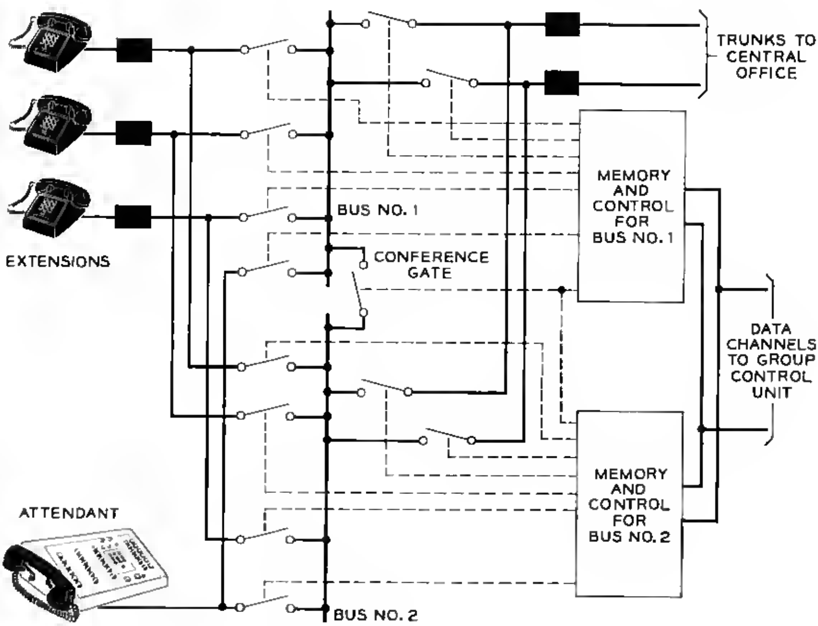

Fig. 43 — 101 ESS switch unit.

Fig. 44 — No. 101 ESS group control unit.

failure would only deny certain special services. A triplicated system clock is located adjacent to the line information store in the next frame.

To the right of the call processor are two bays of input/output equipment which provide buffering between the outlying switch units and the high-speed call processing equipment. These bays also include data transmission equipment to convert data messages to an appropriate form for storage in a ferrite sheet buffer store. At the far right, and in other bays not shown in this picture, are various trunk circuit interfaces with the electromechanical office as well as TOUCH-TONE and dial pulse receivers.

The bays at the far left, including the teletypewriter, provide for system maintenance in a manner analogous to that of No. 1 ESS. The frame mounted on top of the line-up houses special equipment for laboratory test and is not a part of a normal system.

6.4 *Switch Unit*

A photograph of one 200-line switch unit with the doors open is shown in Fig. 45. Part of the electronics is mounted on swinging gates, which provide access to individual line packages inserted in a matrix behind them. Equipment on these gates consists of the duplicated memory and control units as well as certain equipment associated with attendant console operation. Also included are transfer relays used to connect certain office telephones to central office trunks in the event of failure of commercial power at the customer location. The power supplies, which operate from local commercial power, may be seen at the bottom of the cabinet and are of the solid-state variety.

Individual customer line circuits are mounted on plug-in packages behind the swinging gates and provide access to the factory-wired time-division busses. Growth in the number of extensions on a particular switch unit may be easily accommodated by supplying additional plug-in line packages and the appropriate telephone instrument and interconnecting line.

A simplified schematic of a typical line package is shown in Fig. 46. A pair of pnpn diodes provide the time-division gates for each of the two busses. These are connected through a low-pass filter to an input transformer from the station line. Appropriate circuitry is provided for scanning lines for service requests, and a high-power pnpn triode is used for applying ringing current to a standard telephone ringer by-passing the time-division switch.

Sampling of speech on the telephone lines by the time-division switches

Fig. 45 — No. 101 ESS switch unit.

is carried out at a rate of 12.5 kilocycles per second. The duration of the gated signal is approximately 2 microseconds with a total guard interval of 1.2 microseconds. Thus each bus can provide 25 independent time slots in the 80 microseconds between samples of a particular line. The two busses provide 50 time slots for the maximum 200-line capacity of the switch unit. This provides considerably more traffic-handling capacity than is normally encountered in PBX's of this size.

Transmission loss through a pair of line packages is a combination of loss in the line transformer, the low-pass filter, and the resonant transfer

operation. The total insertion loss in this system is approximately 1.5 db, of which most is allocated to the line transformer and filter for economic reasons. Similar reasons dictated the choice of a 12.5 kc sampling rate to reduce low-pass filter cost.

As noted above, the telephone instruments themselves utilize standard 20-cycle ringers. However, the telephone instruments may be of either the rotary dial variety or TOUCH-TONE calling variety, and both types may be connected to a single line if desired. TOUCH-TONE signals are transmitted through the time-division switch to a digit trunk to the group control unit at the central office, where they are detected and registered in memory at that location. For rotary dial telephones, the dc dial pulses are converted to transients which pass through the time-division switch and control a burst of tone over the digit trunk to the control unit. Digit receivers in the central office are designed to distinguish between TOUCH-TONE calling signals and the tone representing dc dial pulses.

The memory in the switch unit is of the circulating type and employs

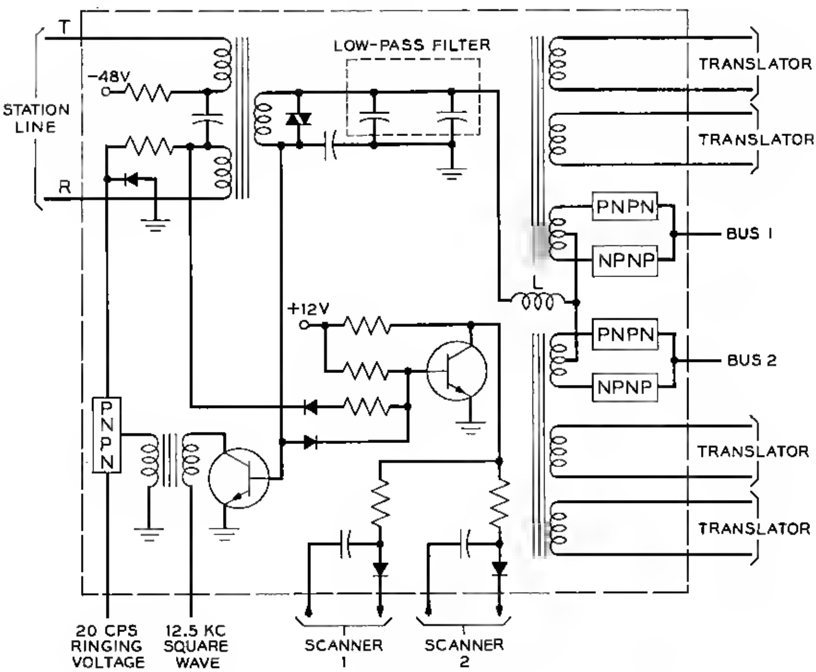

Fig. 46 — No. 101 ESS line circuit.

ferrite cores. When set by an appropriate message from tbe control unit for interconnecting two customers, that connection remains established until a new order is received from the control unit.

A photograph of tbe 200-line switch unit mounted in a reception area with an attendant and TOUCH-TONE calling console is shown in Fig. 47. As noted earlier, larger switch units are under development. These will be supplied to serve up to 340, 800, or 3000 extensions.

6.5 *Field Trial*

To gain field experience with this system, a trial was conducted of a prototype at New Brunswick, New Jersey, during 1963. The group control unit was located in the New Jersey Bell Telephone office in that city, and switch units were provided for two business customers a few miles away. A third switch unit, located in Bell Telepbone Laboratories at Holmdel, New Jersey, about 30 miles from New Brunswick, was connected to the control unit via N-carrier transmission circuits. The trial was carried out over the period from March, 1963, to the end of December, 1963. Equipment used in the trial was essentially identical to tbe production system now being manufactured by Western Electric Company at its Hawthorne plant in Chicago.

Fig. 47 — No. 101 ESS 200-line switch unit and attendant's console.

Some of the features incorporated in the system for this trial are worthy of note. The user is first struck by the speed of response. Provisions for immediate ring make the system very attractive to tbe business customer, even though the time saving may be only a few seconds.

The features most used by our customers in the trial were add-on conference or dial transfer. To establish a conference after two parties were connected required only that one of them momentarily flash his switchhook and dial or key the number of a third conferee. A total of four conferees, one of which could be on an outside trunk, was possible in the trial. The limitation was imposed primarily for transmission reasons, since all customers are effectively connected in parallel. Dial transfer was done in the same way as establishing a conference except that the transferring party would simply hang up after adding the third party.

Another feature, called compressed dialing, was also very popular. Seven- or ten-digit outside numbers could be called by dialing three digits. The identification is made by appropriate magnetic patterns in the twistor module of the line information store in the group control. When the three digits are dialed by the customer, the call processor performs the necessary translation and outpulses the appropriate digits to the distant office. One of the trial customers had a repertoire of 89 compressed numbers with which he could reacb all of bis sales and service offices throughout the United States as well as a number of suppliers with which be frequently conducted business. Tbis list of numbers is common to a switcb unit and can be reached from any extension on that switch unit.

For intra-PBX calling, another service provided abbreviated dialing in which a 1X code could be used to reach six frequently called extensions. Such numbers were provided as a separate list for each telephone extension. In spite of the fact that this code merely reduces tbe dialing from three digits to two digits, only the second digit had to be remembered and not the full extension number. Tbis may account for its very high usage during the trial.

Only six codes were provided for abbreviated dialing, since the codes 17, 18, 19, and 10 were reserved for otber purposes. Code 17 was used for reroute. As described in connection witb the Morris Trial, tbis code permitted an extension user to route his incoming calls to another extension at wbicb he might be reacbed when away from his desk. After receiving dial tone and dialing the code 17, the extension user dialed tbe number of tbe phone to which he wished his calls to be routed. The system acknowledged the receipt of this information by returning a special tone. Thereafter, all calls to that extension would reach the one

designated. When the user returned to his office, he restored service by again dialing the 17 code and receiving the special acknowledgment tone.

The code 18 was used for dial hold. This permitted holding an incoming call without the necessity of providing special buttons on the telephone instrument and key equipment normally required in existing PBX's. If the customer wished to hold a call, he would flash his switchhook, dial 18 to hold the incoming call, and then dial the number of a person with whom he wished to consult. Transfer back and forth between the two parties could be accomplished by a switchhook flash and dialing of the 18 code. If in this process a held party should be forgotten by the original caller, the originating phone was rung back following his disconnect to remind him of this fact. This dial hold feature is attractive in that it does not require a multibutton telephone set, special key equipment and extra wiring as with electromechanical systems.

Code 19 provided a dial pick-up service. In a group office equipped with a number of telephones, it is frequently convenient to provide an arrangement whereby any telephone can pickup any other one in the room. By placing the appropriate pattern of magnetic spots in the line information store, a group of phones may be designated as a pick-up group. When any phone in that group rings, it may be picked up from any other phone by dialing the code 19. Here again, savings result from the use of standard telephone instruments without special key equipment and extra line connections.

The code 10 was used to provide trunk answering from any station when no attendant was present at the console. For example, a night watchman, upon hearing a ring of a special night service bell, could answer the incoming call from the nearest telephone by simply dialing the code 10.

The trial also provided for Direct Inward Dialing to extensions without going through the attendant and Direct Outward Dialing with Automatic Number Identification to distant offices. In the latter case, restrictions could be placed on various lines to prevent direct out-dialing, restrict out-dialing to a specified local area, or provide full access to the Bell System network. The ability to administer this type of restriction at the central office by appropriately magnetizing the twistor cards is another example of stored program convenience.

6.6 *Production and Installation Progress*

Production of No. 101 ESS has been under way at Western Electric's Hawthorne plant in Chicago since 1963. At the beginning of this article,

reference was made to the cut-over of the first system at Brown Engineering and Chrysler Corporation in Cape Kennedy, Florida. The group control unit to serve these customers is located in Southern Bell Telephone Company's office at Cocoa Beach, Florida, where it is associated with a No. 5 crossbar switching office. Four businesses in that area are now (early 1965) being served by that group control. Since the major installation interval for No. 101 ESS is associated with the group control, additional switch units can be added on very short notice and with only a few hours' installation time if the necessary transmission circuits are available.

The second group control produced by Hawthorne was installed for the New York Telephone Company in their Fifty-sixth Street office in Manhattan. It is serving telephone extensions from a switch unit located in the A.T.&T. Co. exhibit at the New York World's Fair. A second switcb unit controlled from New York is serving a group of extensions in the New York Telephone Company's headquarters, and a third provides service to about 180 extensions at Bell Telephone Laboratories, Holmdel.

As noted in the Introduction, installations of group control units have also been completed in Chicago, Cleveland, Los Angeles, and Washington, D. C.

VII. SUMMARY

This article has presented a survey of progress being made by the Bell System in introducing electronic switching into the telepbone plant and has described two systems developed by Bell Telephone Laboratories for this purpose. Present orders indicate that electronic switching is being favorably received by the operating telepbone companies, and customer reactions to the new services have been very encouraging. As production capacity builds up, it can be expected that more and more customers throughout the United States will find these new features available to enhance the value of their telepbone service.

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